

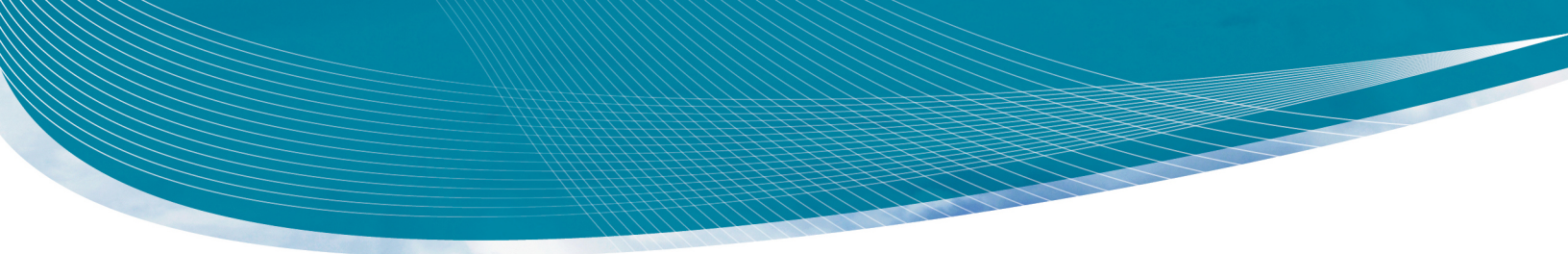
UNITED STATES

Aviation Greenhouse Gas Emissions Reduction Plan



Contents

Executive Summary.....	4
1 Background	8
2 Aircraft and Engine Technology Improvement.....	11
2.1 Program Specifics.....	11
2.1.1 FAA Continuous Lower Energy, Emissions and Noise Program	11
2.1.2 NASA.....	13
2.1.3 Department of Defense	15
2.2 Time Frame and Targets	16
2.3 Expected Emissions Impacts	17
2.4 Success Highlights	17
2.4.1 FAA CLEEN	17
2.4.2 NASA.....	18
2.4.3 Department of Defense	19
3 Operational Improvements.....	20
3.1 Program Specifics.....	20
3.1.1 NextGen	20
3.1.2 NASA.....	21
3.2 Time Frame and Targets	22
3.3 Expected Emissions Impacts	23
3.4 Success Highlights	24
3.4.1 Time Based Flow Management.....	24
3.4.2 Improved Multiple Runway Operations.....	26
3.4.3 Performance Based Navigation.....	26
3.4.4 Separation Management	26
4 Alternative Jet Fuels Development and Deployment	28
4.1 Program Specifics.....	28
4.2 Time Frame and Targets	29
4.3 Expected Emissions Impact.....	30
4.4 Success Highlights	31



5	Policies, Standards, and Measures	33
5.1	CO ₂ Standard	33
5.2	Global Market-Based Measure	34
5.3	NextGen Environmental Management System	34
6	Scientific Understanding and Modeling/Analysis	35
6.1	Analysis Background	36
6.1.1	Forecasting	36
6.1.2	Environmental Modeling	37
6.1.3	System Improvement Assumptions	38
6.2	Analysis Results	39
7	Summary	42

Executive Summary

This action plan provides an overview of the primary initiatives the United States Government (USG)—in partnership with the U.S. aviation industry—is undertaking to reduce greenhouse gas (GHG) emissions from U.S. aviation. The USG is committed to managing the carbon footprint of U.S. aviation while simultaneously enhancing the safety and efficiency of the National Airspace System (NAS). This commitment to reducing environmental impacts is reflected in an aspirational goal of achieving carbon-neutral growth for U.S. commercial aviation by 2020, using 2005 emissions as a baseline. Under the auspices of the Next Generation Air Transportation System (NextGen), the USG has laid out plans and initiatives for improvements in technology and operations; advances in development and deployment of sustainable alternative jet fuels; and policies, standards, and selective measures to incentivize transition of the fleet and airspace system. This action plan details the specific programs being pursued under these areas, their expected emissions impacts, and notable achievements thus far. The USG has prepared this plan as an update to the 2012 *United States Aviation Greenhouse Gas Emissions Reduction Plan*. This plan includes both domestic and international aviation. The domestic reductions are reflected in the national contributions submitted by the U.S. to the United Nations Framework Convention on Climate Change (UNFCCC). This plan also discusses ongoing work to better understand and model the environmental impacts of aircraft, including climate impacts, and presents an analysis that projects the future environmental performance of the NAS and shows the potential for significant environmental benefit from the aviation system improvements that are described in the document. Below are some of the key elements of this action plan.

Aircraft and Engine Technology Improvement

The Continuous Lower Energy, Emissions, and Noise (CLEEN) program, launched by the FAA in 2010, is a collaborative partnership with industry to accelerate development and deployment of environmentally promising aircraft technologies and sustainable alternative jet fuels. Technologies matured under the CLEEN program are anticipated to begin entering the commercial fleet in 2016. CLEEN II, a follow-on program to CLEEN, will solicit new technology concepts expected to be on a path for introduction into commercial aircraft before 2026.

The National Aeronautics and Space Administration (NASA) and the U.S. Air Force continue to push research and exploration of environmentally sustainable aviation technologies. NASA does this primarily through its Environmentally Responsible Aviation (ERA) and Advanced Air Transport Technology (AATT) projects, which focus on new vehicle technologies that have the potential to significantly reduce aviation's impact on the environment. The U.S. Air Force, meanwhile, conducts research and testing into vehicle efficiency improvements (e.g., through the Adaptive Engine Technology Development program) that can often transition into development of commercial products that are utilized by the civil fleet.

Operational Improvements

Implementation of NextGen will allow for more efficient aircraft operations and reduced GHG emissions through operational improvements. Many foundational and infrastructure elements are expected to be in place in the near-term, providing critical NextGen capabilities or infrastructure upon which future NextGen capabilities will be built. In coordination with the aviation industry, the FAA has established key priorities and developed an implementation plan to deliver high priority, high readiness capabilities in four focus areas: Multiple Runway Operations, Performance Based Navigation (PBN), Surface Operations, and Data Communications (Data Comm). The FAA has already introduced a large number of PBN procedures into the NAS through the Metroplex program. The NASA Airspace Operations and Safety Program supports NextGen through the development and demonstration of integrated Air Traffic Management technologies. These programs, among others, have provided and will continue to provide operational benefits to the NAS resulting in reductions in fuel burn and emissions.

Alternative Jet Fuels Development and Deployment

The USG is actively supporting and facilitating the development and deployment of sustainable alternative jet fuels with lower life-cycle GHG emissions than conventional petroleum fuel. Interagency coordination and industry collaboration is central to the USG work in this area. The Farm to Fly 2.0 cooperation agreement and the Commercial Aviation Alternative Fuels Initiative (CAAFI) are two primary examples—the former focuses on supply chain and production infrastructure creation; the latter, on research and development, environmental assessment, fuel testing, demonstration, and commercialization. Thus far, the standard setting organization ASTM International has approved three alternative jet fuels for use in aviation. Research is ongoing to pursue additional approvals and also to examine the viability of regional supply chains and chart a path for overcoming barriers to production. These joint initiatives are paving the way to large-scale production and broad commercial use of alternative jet fuels, thereby providing greater opportunity to meet U.S. environmental goals.

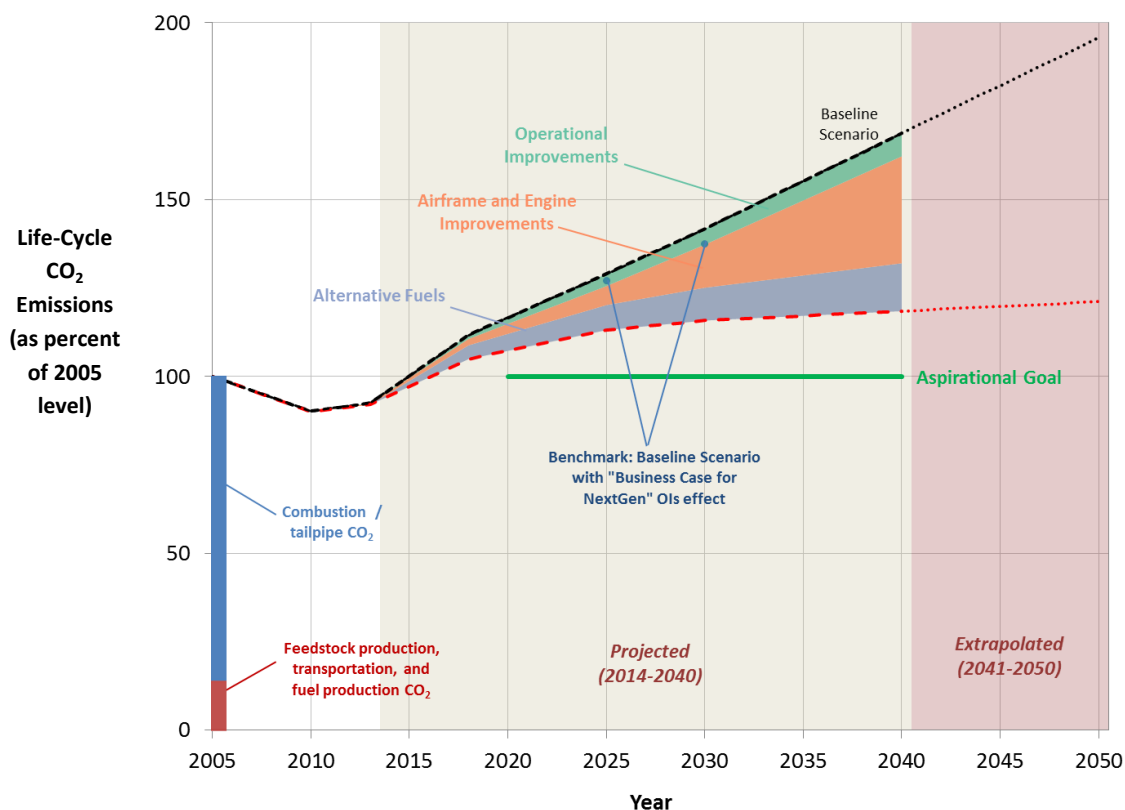
Policies, Standards, and Measures

The USG is pursuing the development of policies, standards, and measures that would supplement efforts in technology, operations, and alternative jet fuels to further reduce aviation emissions. The USG is focused on two items, in particular: (1) the development of a meaningful CO₂ standard in ICAO for implementation in the U.S., and (2) working with ICAO on the development of a proposal for a Global Market-Based Measure (GMBM) to serve as a gap filler to address international aviation GHG emissions. The USG is actively engaged, participating, and providing resources towards the successful development and implementation of these policy elements.

Scientific Understanding and Modeling/Analysis

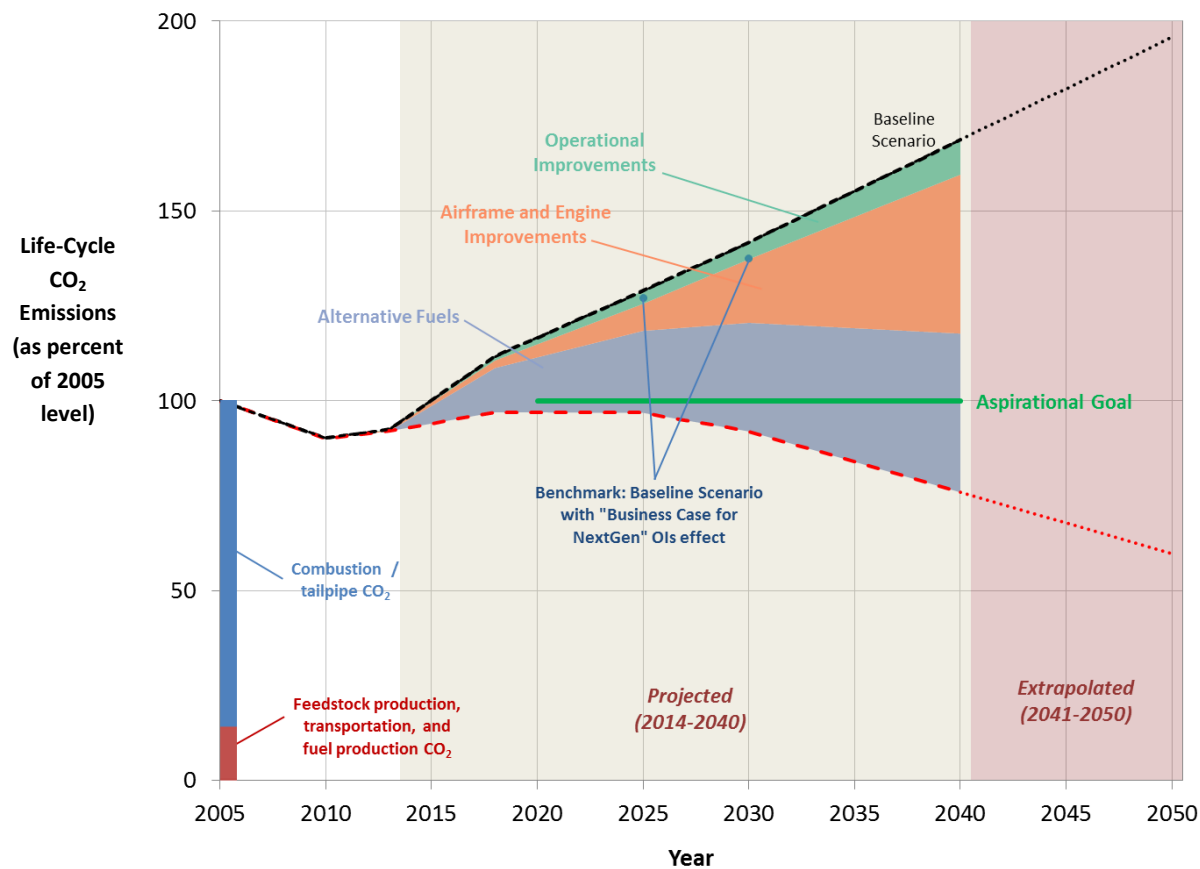
The FAA is continually improving its modeling and analysis tools in order to better understand and assess the environmental impacts of aviation. One analysis conducted by the FAA explores how system improvements (e.g., operational changes, technology improvements, alternative jet fuel usage) will help propel the FAA towards environment and energy goals. The below figures present projections of CO₂ emissions along with potential reductions given moderate and aggressive assumptions for technology evolution and alternative jet fuel availability. The analysis indicates that significant progress can be made toward the USG's aspirational climate goals through aviation system improvements. Challenges remain to the development and deployment of the operational improvements, technology improvements, and alternative fuel quantities reflected in these scenarios, and it will take concerted USG and aviation industry efforts to work through these challenges in pursuit of environment and energy goals. As the underlying tools and assumptions are improved, this analysis will be refined and updated.

Figure ES-1 Projected life-cycle CO₂ emissions impacts – moderate system improvement scenario¹



¹ Note that combustion/tailpipe emissions are those created by the airline industry, while feedstock production, transportation, and fuel production emissions for conventional jet fuel are created by the petroleum extraction and refining industries. The emissions from alternative jet fuels would result in a net reduction in the CO₂ emissions from fuel production and use. The scenario does not imply that the upstream emissions are attributable to airlines, rather than to jet fuel producers and others in the supply chain.

Figure ES-2 Projected life-cycle CO₂ emissions impacts – aggressive system improvement scenario





01 Background

The United States Government (USG) is committed to addressing the climate change impacts of domestic and international commercial aviation, and is pursuing a multi-pronged approach to achieve greenhouse gas (GHG) emissions reductions. In support of these efforts, the U.S. Federal Aviation Administration's (FAA) Office of Energy and Environment (AEE) works collaboratively with the International Civil Aviation Organization (ICAO) as well as its Committee on Aviation Environmental Protection (CAEP) to address aviation's impact on the environment. The FAA supports the policy work of ICAO and the technical work conducted in CAEP in partnership with the Department of State, Environmental Protection Agency and other federal agencies.

In October 2010, the 37th ICAO Assembly adopted a comprehensive climate change resolution committing to reducing GHG emissions from international aviation. A central element of Resolution A37-19 was for States to voluntarily prepare and submit action plans for reducing international GHG emissions to ICAO. In response to this request, the USG released the *United States Aviation Greenhouse Gas Emissions Reduction Plan*² in June 2012 to communicate U.S.

² *United States Aviation Greenhouse Gas Emissions Reduction Plan* (2012) available at http://www.faa.gov/about/office_org/headquarters_offices/apl/enviro_policy_guidance/policy/media/Aviation_Greenhouse_Gas_Emissions_Reduction_Plan.pdf

aviation plans and initiatives on climate change and to help ICAO track progress towards reaching global goals. The 38th ICAO Assembly's climate change resolution (A38-18)—adopted in October 2013—further encourages States to submit action plans to ICAO. The USG has prepared this GHG emissions reduction plan as an update to the 2012 document. This plan includes both domestic and international aviation. The domestic reductions are reflected in the national contributions submitted by the U.S. to the United Nations Framework Convention on Climate Change (UNFCCC). This plan and U.S. involvement in ICAO's work also reflect U.S. domestic priorities as outlined by *The President's Climate Action Plan*³, released in June of 2013. *The President's Climate Action Plan* highlights the need to develop and deploy advanced transportation technologies in response to climate change and emphasizes the importance of forging global solutions to climate change through continual dialogue and cooperation between nations.



The FAA, in its *Aviation Environmental and Energy Policy Statement*⁴, has set an aspirational goal of achieving carbon-neutral growth for U.S. commercial aviation by 2020, using 2005 emissions as a baseline. The USG has already made progress in reducing GHG emissions within the aviation sector through energy efficiency improvements and through public-private partnerships. The USG is on a trajectory to continue that progress in coming years.



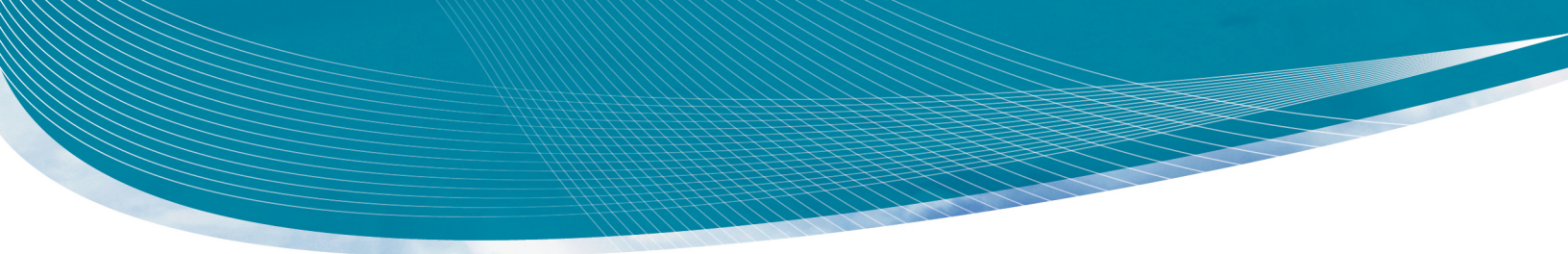
Under the auspices of the Next Generation Air Transportation System (NextGen), the USG has laid out plans and initiatives for implementing a five-pillar strategy to address aviation environmental and energy issues. This plan identifies actions and progress toward GHG emissions reductions in each of these areas:

- Aircraft and Engine Technology Improvement
- Air Traffic Management Operational Improvements
- Alternative Jet Fuels Development and Deployment
- Policies, Standards, and Measures
- Scientific Understanding and Modeling/Analysis

The following sections in this plan detail the measures that the USG is pursuing under these pillars to reduce aviation GHG emissions, expanding on program specifics, time frame and targets, expected emissions impacts, and success highlights. The USG has also undertaken a system-level analysis to estimate projected CO₂ emissions reductions from technology, operations, and alternative jet fuels in order to assess progress toward the carbon-neutral

³ *The President's Climate Action Plan* available at <http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf>

⁴ *Aviation Environmental and Energy Policy Statement* available at http://www.faa.gov/about/office_org/headquarters_offices/apl/enviro_policy_guidance/policy/media/FAA_EE_Policy_Statement.pdf



growth goal for U.S. commercial aviation and to assess the need for further progress through mechanisms such as policies, standards, and measures. The results of this analysis are presented in Section 6, Scientific Understanding and Modeling/Analysis.



02 Aircraft and Engine Technology Improvement

The evolution of modern, more fuel-efficient airframes and engines has produced the most significant aviation emissions reductions historically and will drive more reductions in the future. The USG is leading a number of efforts and collaborating with the aviation industry to develop and improve technology that results in better fuel efficiency and reduced emissions. USG actions to improve aircraft and engine technology are carried out among others by the FAA, the National Aeronautics and Space Administration (NASA), and the Department of Defense (DOD) and are coordinated through the National Aeronautics Research and Development Plan.⁵

FAA, NASA, and DOD are leading a number of efforts and collaborating with industry to develop and improve fuel-efficient, emissions-reducing technology.

2.1 Program Specifics

2.1.1 FAA Continuous Lower Energy, Emissions and Noise Program

⁵ National Aeronautics Research and Development Plan available at <http://www.whitehouse.gov/sites/default/files/microsites/ostp/aero-rdplan-2010.pdf>



The Continuous Lower Energy, Emissions, and Noise (CLEEN) program, launched by the FAA in 2010, is a collaborative partnership with five aviation manufacturers (Boeing, General Electric, Honeywell, Pratt & Whitney, and Rolls-Royce) to develop technologies that will reduce noise, emissions, and fuel burn; to enable alternative jet fuel use; and to expedite integration of these technologies into current and future aircraft. CLEEN is focused on the complete aircraft and includes airframe, propulsion, and aircraft control technologies. Over the last five years, the total federal investment in the CLEEN program has been more than \$117 million. With participating aviation manufacturers exceeding the one-to-one cost share requirement, the overall investment in the program has exceeded \$250 million. Technologies matured under the CLEEN program are anticipated to begin entering the commercial aircraft fleet in 2016.⁶ These technologies are described in the following sections.

Boeing

Boeing is developing and demonstrating two aircraft technologies that reduce fuel burn and noise. The two technologies being examined by Boeing are an Adaptive Trailing-Edge on the aircraft wing and a Ceramic Matrix Composite (CMC) acoustic nozzle at the engine exhaust. The Adaptive Trailing-Edge is a technology that deploys miniature flaps to improve wing aerodynamic efficiency and decrease noise during approach. The CMC engine nozzle can withstand higher temperatures and is made of lighter weight material, thus reducing fuel consumption. It also includes acoustic treatments that reduce community noise.

General Electric

General Electric (GE) is developing and demonstrating multiple aircraft technologies that will reduce fuel burn, emissions, and noise. The Open Rotor engine, consisting of dual counter-rotating propellers driven by a gas turbine, can deliver fuel burn reductions due to the lower fan pressure ratio that it can achieve. An advanced engine combustor known as the Twin Annular Premixed Swirler (TAPS) II can significantly reduce NO_x emissions. GE is also developing Flight Management System advances that will enable more efficient aircraft trajectories and improved engine monitoring and performance.

Honeywell

Honeywell is developing and demonstrating technologies that will increase engine efficiency and reduce engine weight. These technologies include new coatings, an impeller that can withstand higher temperatures, advanced low leakage air seals, and improved turbine cooling. These advances enable the engine to run at higher temperatures in the compression and turbine system, thereby increasing cycle thermal efficiency.

⁶ More information about the CLEEN program available at http://www.faa.gov/about/office_org/headquarters_offices/apl/research/aircraft_technology/cleen/

Pratt & Whitney

Pratt & Whitney is developing and demonstrating advanced technologies that will enable an ultra-high bypass ratio geared turbofan (GTF) engine. GTF engine technologies will contribute to reduced aircraft noise and fuel consumption through increased engine efficiency.

Rolls-Royce

Rolls-Royce is developing and demonstrating two technologies aimed at increasing thermal efficiency in the turbine section of the engine: Dual-Wall Turbine Airfoil and CMC Blade Track. Dual-wall turbine airfoils are projected to provide 20 percent or more reduction in cooling and increased operating temperature capability. The new blade tracks made from CMC material are projected to offer more than a 50 percent reduction in engine cooling and weight savings compared to a metallic design. These efficiency improvements will lead to reductions in fuel consumption.

CLEEN II

The FAA is pursuing a follow-on program to continue maturing and accelerating environmentally beneficial aircraft technologies and alternative jet fuels after the conclusion of the CLEEN program. This program, CLEEN II, will solicit new aircraft technology concepts that are expected to be on a path for introduction into commercial aircraft before 2026. This is an entirely new competitive selection and award process, like CLEEN went through in 2010. Similar to CLEEN, CLEEN II will be a five year program starting in 2015 and expected to run to 2020 with a focus on reducing aircraft fuel burn, noise, and emissions and advancing the development of alternative jet fuels.

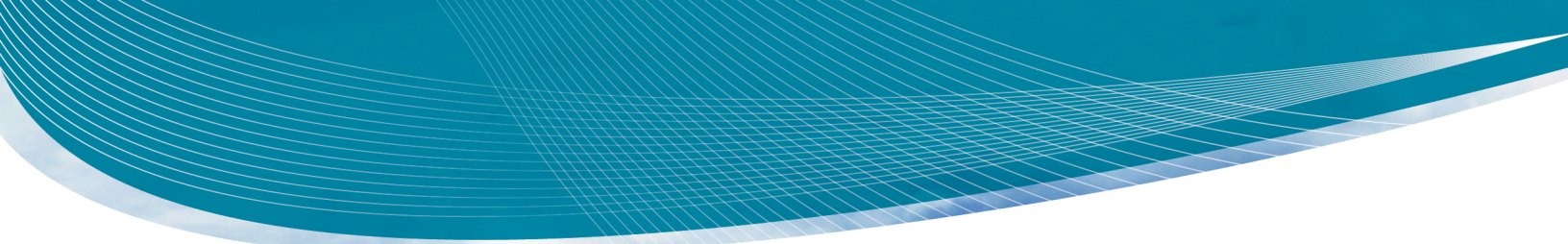
2.1.2 NASA



The NASA Advanced Air Vehicles Program and Integrated Aviation System Research Program both conduct research on new vehicle technologies that will have a significant impact on reducing emissions. NASA does not build engines or engine components, but rather, NASA programs and research generate advanced technologies and knowledge. Typically five to ten years after the conclusion of a NASA program, industry will build on NASA's research results and integrate the associated knowledge into commercial products. A sample of some of the research focused on vehicle efficiency improvements and emissions reduction is described below.

Vehicle Efficiency Research

The Environmentally Responsible Aviation (ERA) Project's goal is to reduce the impact of aviation on the environment through the development of vehicle concepts and technologies that can simultaneously reduce aircraft fuel burn, noise, and emissions. The project is focused on maturing and demonstrating integrated technologies in a relevant environment to accelerate the technology transition for use in subsequent transport category aircraft and



engine programs. The research is conducted through a series of integration technology demonstrations that will provide viable solutions to the project's goals between now and 2025.

One focus area for the NASA ERA Project is developing new laminar flow technologies—i.e., technologies that reduce drag through smooth, non-turbulent airflow. The first technology in this area is an active flow control (AFC) enhanced vertical tail, which entails sizing the vertical stabilizer for conventional operating conditions—thus reducing weight and drag—while still providing the required performance to meet critical engine out situations during takeoff using actuators that blow air across the rudder surfaces. The second technology is the development and testing of insect residue accretion protection surface coatings. These coatings will help maintain smooth airflow over the wing and reduce drag. The research will advance the Technology Readiness Level (TRL) of these two drag reduction technologies for aircraft applications to the point where they can be integrated into the next generation of aircraft.

Another focus area for the ERA Project is the development of new lighter weight structures. The purpose of this research is to advance the TRL of advanced composite technology for aircraft applications to the point where it can be integrated into the next generation of aircraft. This research addresses the need for composite technologies that reduce weight and enable reduced drag configurations including high aspect ratio wings and advanced aircraft concepts.

A third area of focus for the ERA Project portfolio is the testing of a wing design equipped with adaptive compliant trailing edge technology—i.e., flexible trailing-edge wing flaps. Integration of compliant structures in next generation aircraft will reduce weight and drag, contributing to a reduction in fuel burn. Flight tests will demonstrate and establish airworthiness for a compliant structure used as a large primary control surface in a relevant flight environment and accelerate the infusion of this technology.

The NASA Advanced Air Transport Technology (AATT) Project (formerly the Fixed Wing Project) explores and develops technologies and concepts to enable revolutionary advances in vehicle and propulsion system energy efficiency and environmental compatibility. This portfolio includes research in aerodynamic, structural, and propulsion efficiency; noise and emissions reduction; and integrated system concept exploration.

One research focus area for the AATT Project is the development of aerodynamic and structures technologies that enable an increase in the optimal wing aspect ratio by 50-100 percent—reducing weight and drag—while preserving structural safety and flight control. NASA is researching a truss-braced wing, a future generation transport aircraft concept that is designed to be aerodynamically efficient by employing a high aspect ratio wing design. Additionally, NASA continues to investigate the potential for new configurations to greatly improve efficiency. One area of related research conducted by the AATT Project seeks to achieve a vehicle-level net system benefit with a distortion-tolerant inlet/fan, boundary-layer ingesting (BLI) propulsion system on a representative vehicle. The goal is to capture the

significant energy efficiency and emissions benefits of vehicle drag reduction from BLI while minimizing potential propulsion system losses from a practical BLI application.

Emissions Reduction Research

Under the first phase of the ERA Project, NASA worked with various partners to develop fuel flexible combustor concepts capable of reducing landing and takeoff cycle (LTO) nitrogen oxide (NO_x) by 75 percent relative to the CAEP/6 standard.⁷ After evaluations of multiple concepts, both GE and Pratt & Whitney demonstrated the potential of meeting this challenging NO_x reduction goal through high pressure sector rig testing. GE tested an advanced version of a lean burn concept with heritage from their Twin-Annular Premixing Swirler (TAPS) combustor. Pratt & Whitney tested an axially-controlled stoichiometry concept that exceeded the established goals.

Under the AATT Project, NASA has set a goal of more than 80 percent NO_x reduction relative to the CAEP/6 standard, but achieved in smaller, higher operating pressure engines. The objective of the research is to investigate small engine core scaling, fuel injection, and thermal growth management technologies needed for obtaining this challenging goal in advanced engine cycles. Alternative jet fuels flexibility is also a key driver as NASA looks into capitalizing on the potential of these fuels to reduce particulate matter emissions.

Currently, NASA is involved in technology development for advanced, small core engines. NASA is working on several techniques for active combustion control, including Lean Direct Injection (LDI). Lean-burn has an unmatched advantage in terms of particulate matter and NO_x reduction in the cruise phase. NASA also conducts foundational research to better understand combustion physics, including developing and validating physics-based combustion models against gaseous-fuel and liquid-fuel experiments.

2.1.3 Department of Defense

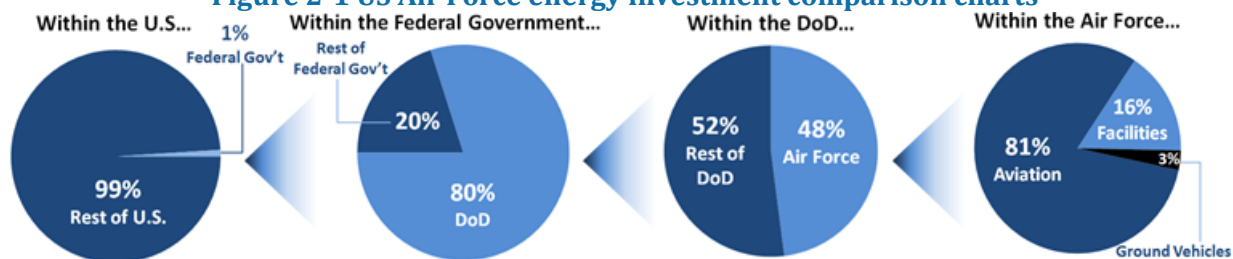


The United States Air Force's mission is an energy-intensive undertaking. To execute a mission of global vigilance, reach, and power, the Air Force focuses on four energy priorities: improve resiliency, reduce demand, assure supply, and foster an energy aware culture.

The Air Force makes a sizable investment each year in energy. Figure 2-1 below puts this into context: the Department of Defense consumes the most fuel within the Federal Government and the Air Force consumes roughly half of that use (\$9B in 2013). Air Force aviation accounts for over 80 percent of that amount.

⁷ CAEP/6 NO_x standard: ICAO, "Aircraft Engine Emissions," Annex 16, Volume II, Third Edition, July 2008, Amendment 7. Copies of this document can be obtained from the ICAO website at <http://www.icao.int/>.

Figure 2-1 US Air Force energy investment comparison charts



The Air Force targets vehicle efficiency improvements through programs in three primary areas: (1) improved aerodynamics, (2) weight reduction, and (3) increased engine efficiency. Surfing Aircraft Vortices for Energy (\$AVE) formation flight technology decreases fuel consumption while in formation by harvesting energy from the leader aircraft's wingtip vortices. In Air Force flight tests, precision flying in the wake of a leading aircraft at an operationally realistic and safe distance enabled an 8-10 percent fuel savings for the trailing aircraft. Examples of weight reduction include removing redundant or unnecessary equipment, applying precise fueling loads, and replacing heavy items, such as publications and technical orders with electronic flight bags. Several engine efforts are underway to upgrade existing power plants, while new designs stemming from the Adaptive Engine Technology Development (AETD) program are scheduled to be incorporated in the F-35 fighter fleet engine upgrade in 2023; these upgrades translate to a 25 percent fuel consumption reduction, potentially saving over 1 billion gallons of fuel by 2040. Research and testing performed in these military programs can often transition into development of commercial products that are utilized by the civil fleet. For instance, DOD research evaluating CMC materials for gas turbine engines has helped accelerate the overall development of CMC technology for aerospace, thus making it more viable for commercial purposes.

2.2 Time Frame and Targets

The FAA CLEEN, NASA ERA Project, NASA AATT Project, and DOD's AETD program goals are complementary in their reduction targets and their timeframes.

- A primary aspirational goal of the CLEEN program is to develop and demonstrate, by 2015, technology that reduces fuel burn by 33 percent relative to current technology and reduces LTO NO_x by 60 percent relative to the CAEP/6 standard. The technology would then be available for commercialization.
- CLEEN II's efficiency goal is to develop and demonstrate certifiable aircraft technology that reduces aircraft fuel burn by 40 percent relative to year 2000 best-in-class in-service aircraft, and/or supports the FAA goal to achieve a net reduction in climate impact from aviation. The LTO NO_x goal is to reduce by 75 percent relative to the CAEP/6 standard, and/or reduce absolute NO_x production over the aircraft's mission. Following a similar model to the CLEEN program, the technology will be matured by

2020 to the point where it can be entered into product development for eventual deployment into the fleet.

- The NASA ERA Project has a goal to reduce mission fuel burn by 50 percent not later than 2020 for subsonic passenger and cargo transport aircraft.
- The NASA AATT Project intends to mature technology associated with emerging aircraft and engine designs slated for introduction into the fleet beyond 2030 with the goal of decreasing fuel burn by 70 percent.
- The DOD AETD program has a goal of a 25 percent improvement in fuel efficiency for military engines by 2020. Some of the military engine fuel efficiency technologies will find their way into the civil fleet.

2.3 Expected Emissions Impacts

The technologies described above are currently being advanced by industry investment as well as FAA, NASA, and DOD funded research. Continued successful maturation of these technologies through public-private partnerships and subsequent commercialization by industry could yield significant fuel efficiency improvements on the order of 50 to 70 percent below current levels.

2.4 Success Highlights

2.4.1 FAA CLEEN

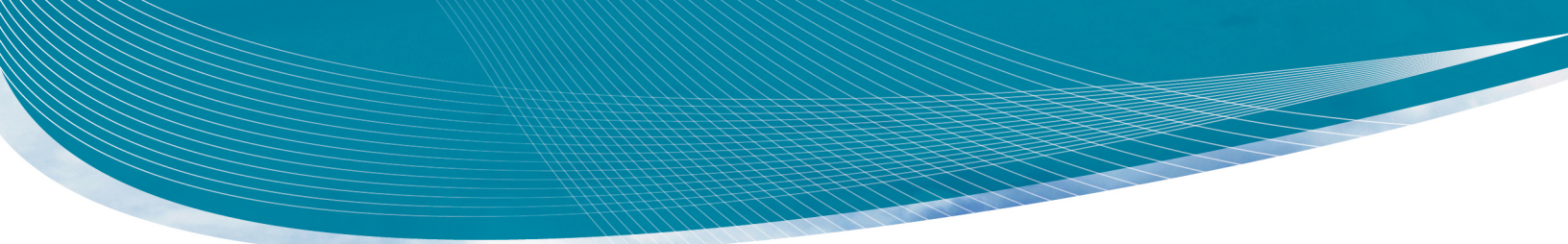
In partnership with industry, CLEEN is already accelerating development of aircraft technologies that reduce fuel burn. Below are some of the program achievements through FY2014.

Boeing

In August and September 2012, Boeing's "ecoDemonstrator" flight tests demonstrated Adaptive Trailing-Edge technology. Under an agreement with American Airlines, these tests used one of the airline's 737-800 models for flight testing in Glasgow, MT. The Adaptive Trailing-Edge technology has the potential for 2 percent fuel burn savings and 1.5 EPNdB cumulative noise reduction in single and twin aisle configurations. In spring 2013, Boeing completed ground testing of its Ceramic Matrix Composite (CMC) engine nozzle. In July 2014, this technology was successfully flight tested on the Boeing 787 "ecoDemonstrator." The CMC nozzle has the potential for 1 percent fuel burn savings—enabling hotter, more efficient engines—while allowing for noise reduction treatment and reducing nozzle weight.

GE

In January 2012, GE completed core engine tests of the TAPS II Combustor. Results show LTO NO_x emissions were reduced 60 percent compared to the ICAO NO_x standard adopted in 2004,



meeting one of the CLEEN goals. This combustor will be used in CFM International's LEAP turbofan engine and is expected to enter service in 2016. In January 2012, GE completed scaled Open Rotor wind tunnel tests. Results indicate aircraft fuel burn on a single aisle aircraft may be reduced 26 percent relative to a CFM International, CFM56-7B engine, and cumulative noise may be reduced by up to 15 dB relative to FAA Stage 4 (ICAO Chapter 4) noise standards. In March 2013, GE demonstrated flight trajectory synchronization between aircraft and the En Route Automation Modernization (ERAM) system. Trajectory synchronization will provide pilots and controllers better predictability of an aircraft's location, enabling fuel savings through more efficient aircraft routing.

Honeywell

From 2012 through 2014, Honeywell completed engine tests of a number of its CLEEN technologies, validating their capability of increased engine temperature and efficiency. Honeywell plans to continue engine ground tests of the remaining technologies through 2015. The Honeywell CLEEN technologies will contribute 5 percent toward an overall 15.7 percent reduction in fuel burn resulting from an engine upgrade relative to baseline engine technology.

Pratt & Whitney

In June 2012, Pratt & Whitney began NASA wind tunnel tests of an advanced fan for an ultra-high bypass ratio geared turbofan engine. Results were used to validate the CLEEN geared turbofan engine design. Further wind tunnel tests and an engine ground test of the GTF engine are scheduled for 2015 and 2016. This engine is projected to reduce single aisle aircraft fuel consumption by 20 percent relative to a CFM International, CFM56-7 engine and reduce noise by 25 dB relative to the Stage 4 noise standards.

Rolls-Royce

In July 2011, Rolls-Royce completed CMC turbine blade tracks (shrouds) component tests. Engine testing of this technology began in spring 2013. This technology, along with Rolls-Royce's dual wall turbine vane, is aimed at increasing thermal efficiency in the turbine section of the engine. Technology benefits from Rolls-Royce's work will realize up to a 1 percent reduction in fuel consumption.

2.4.2 NASA

Building on work performed during the first phase of the ERA Project, NASA has selected eight large-scale integrated technology demonstrations⁸ to advance ERA research. This phase of the research is focused on five areas: aircraft drag reduction through innovative flow control concepts; weight reduction from advanced composite materials; fuel and noise reduction from advanced engines; emissions reductions from improved engine combustors; and fuel

⁸ List of integrated technology demonstrations available at http://www.nasa.gov/topics/aeronautics/features/blue_skies_green.html#.VMJhby6fiWs

consumption and community noise reduction through innovative airframe and engine integration designs. These flight and ground technology tests aim to further the project's goals of simultaneous reductions in fuel, emissions, and noise from commercial transport planes. As an example, in 2014, NASA and the U.S. Air Force Research Laboratory began flight testing of the adaptive compliant trailing edge—a technology that will reduce wing structural weight and give engineers the ability to aerodynamically tailor the wings to promote improved fuel economy and more efficient operations. This and other ERA demonstrations are expected to continue through 2015. Under the AATT Project, tests in the NASA Langley Transonic Dynamics Tunnel of concepts such as a truss-brace configuration and boundary-layer ingesting propulsion systems are validating prior analyses showing the potential of these technologies for fuel burn reduction and environmental benefits.

2.4.3 Department of Defense

Since 2010, the Air Force has consumed over 9 billion gallons of fuel. Table 2-1 below shows a decrease each year in fuel consumption. This decrease is due to both a reduction in flying hours resulting from a reduction in mission and increased efficiencies from technology and operational improvements. Air Mobility Command, the Air Force's largest fuel consumer, was able to achieve gains of 8 percent (with a commensurate avoidance of over 800,000 metric tons CO₂e) through its efforts in 2013. These reductions are not part of the U.S. action plan; however, they do highlight the commitment of the United States to reduce emissions associated with aviation fuel use.

Table 2-1 US Air Force fuel consumption per year

Year	Fuel	GHG Emissions (Jet Fuel only)
FY2010	2.51 billion gal	24.5 MMT CO ₂ e
FY2011	2.45 billion gal	23.9 MMT CO ₂ e
FY2012	2.25 billion gal	22.0 MMT CO ₂ e
FY2013	1.96 billion gal	19.1 MMT CO ₂ e

Note: Calculated using White House CEQ/DOE FEMP FY14 Annual Energy Management Report/Greenhouse Gas Reporting Tool, reported in Million Metric Tons CO₂ equivalent (MMT CO₂e).



03 Operational Improvements

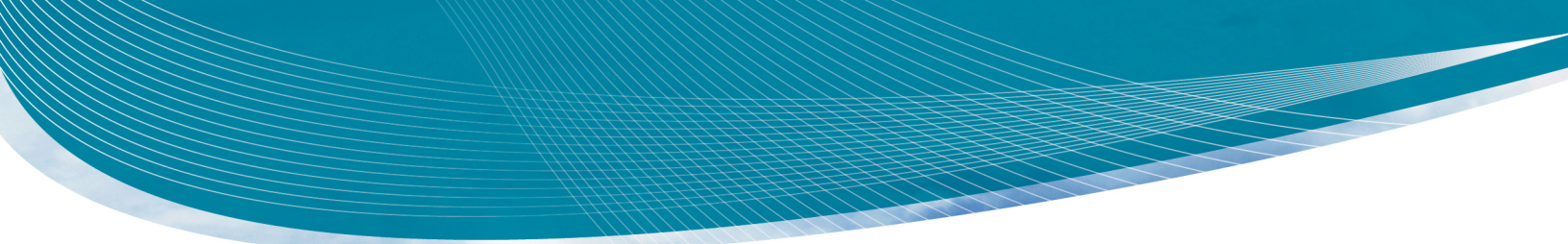
Achieving more efficient aircraft operations is another critical element for reducing GHG emissions from aviation. The FAA is implementing a comprehensive, multi-year overhaul of the NAS known as NextGen. While the benefits of NextGen are many and go well beyond environment, among the key elements of NextGen are reducing delays, establishing more precise routes, and improving overall efficiency of the NAS, all of which can contribute to reduced fuel burn and emissions.

3.1 Program Specifics

3.1.1 NextGen

Implementation of NextGen will allow for more efficient aircraft operations and reduced GHG emissions through operational improvements. With NextGen foundational and infrastructure elements in place by the end of 2015, benefits are expected to increase incrementally as NextGen procedures are implemented and operators equip for those procedures. In 2014, the FAA completed the baseline ground infrastructure for Automatic Dependent Surveillance-Broadcast (ADS-B), the satellite-based successor to radar that provides increased

Implementation of NextGen will allow for more efficient aircraft operations and reduced GHG emissions through operational improvements.



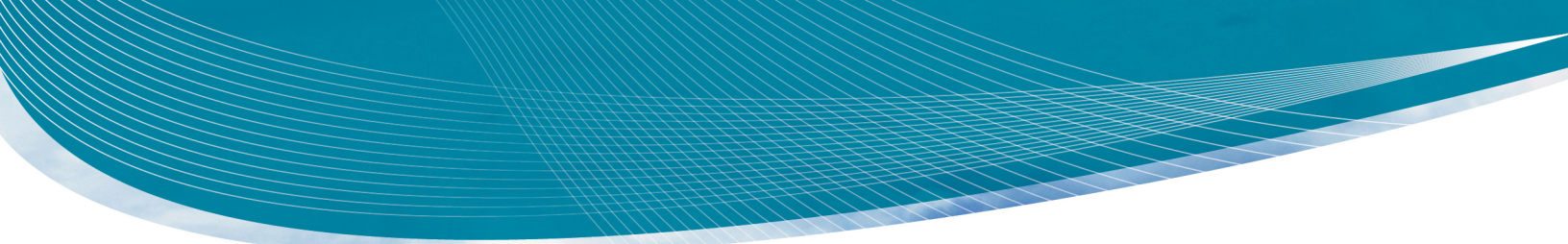
situational awareness and airspace efficiency. En Route Automation Modernization (ERAM) is replacing the legacy HOST automation system that the FAA has used to control high-altitude airspace since the 1970s. ERAM will increase air traffic flow and improve automated navigation and conflict detection services. Under the Terminal Automation Modernization and Replacement (TAMR) program, similar upgrades are being made to the automation platform used to control low-altitude airspace near airports. These are some of the programs that are either providing critical NextGen capabilities or providing the infrastructure upon which critical NextGen capabilities will be built. This technological foundation will allow the NAS to operate with greater efficiency, increased predictability, and reduced environmental impact. There are a variety of implemented and planned operational improvements under NextGen that reduce CO₂ emissions through mechanisms such as reduced track miles flown and more efficient routing. These programs are discussed in later sections.

3.1.2 NASA

The NASA Airspace Operations and Safety Program conducts a broad range of research focused on improving the performance and efficiency of the Air Transportation System. This research focuses on various phases of operations including surface, terminal, and en route. Results of NASA's research to define and validate the Efficient Descent Advisor (EDA) concept were officially transferred in FY2012 to the FAA for further evaluation and potential operational use. The EDA concept helps air traffic controllers allow airliners of all sizes to more efficiently descend from cruising altitude to arrive at an airport using less engine power while maintaining a safe distance from other aircraft. As a result, airlines save money on fuel, fewer emissions are released into the atmosphere, and air traffic controller workload is reduced (since automation is added to the process). In fact, NASA simulations showed a potential annual savings of \$300 million in fuel. Technology based on NASA's EDA concept is scheduled to be deployed as part of the FAA's Trajectory Based Flow Management (TBFM) program.

The Airspace Systems Program continued progress towards Air Traffic Management Technology Demonstration-1 (ATD-1), which will showcase an integrated set of technologies that provide an efficient arrival solution for managing an aircraft's descent from cruising altitude all the way down to the runway. One of the ATD-1 tools, Terminal Sequencing and Spacing (TSS), was transferred to the FAA in July 2014. TSS technology provides information to controllers about the speeds they should assign to aircraft as they follow more fuel-efficient, continuous-descent approaches into airports, saving both time and fuel while reducing emissions. Results demonstrate user operational benefits through the integration of ADS-B enabled Flight Deck Merging and Spacing; Terminal Area Precision Scheduling; and Controller-Managed Spacing for increased throughput and efficiency with a benefit potential of \$500M/year if deployed by 2020.

NASA has conducted human-in-the-loop simulations of advanced trajectory-based algorithms that reduce aircraft delays during taxi as part of its Spot and Runway Departure Advisor (SARDA) project. Delays on the airport surface are one of the major factors limiting the ability



of airports to accommodate high levels of surface traffic throughput. These algorithms include a more advanced surface movement planning horizon (up to one hour) leading to reduced surface congestion. Benefits studies for several complex U.S. airports show a taxi delay reduction of between three to five minutes resulting in annualized fuel savings of \$2.5 million to \$7.5 million at each airport using these algorithms. Technology transition to the FAA may occur as early as 2015.

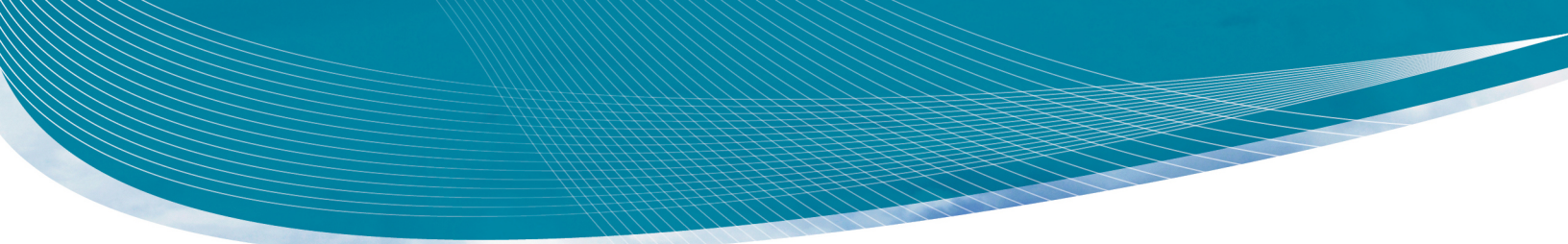
NASA is collaborating with the FAA to explore the use of NASA's Precision Departure Release Capability (PDRC) that couples advanced airspace flow management and airport surface traffic tools. PDRC allows precision scheduling of departing aircraft to allow for smooth integration into available slots in the high-altitude overhead streams. Missed departure slots in the overhead stream translate to departure delays and lost system capacity. The technology automates what is today an inefficient manual process for negotiating a take-off time between the control tower and en route control center. As compared to today's process, NASA expects take-off time conformance to double in improvement, representing an estimated \$20 million in annual system-wide savings. NASA successfully transferred the PDRC technology to the FAA in 2013.

Bad weather causes seventy percent of air traffic delays. Until now, airline dispatchers and FAA traffic managers did not have a way to continuously reevaluate the pre-departure weather avoidance routes for each flight. NASA's Dynamic Weather Rerouting (DWR) tool enables dynamic, "real-time" adjustments to flight paths to avoid bad weather with minimum delay while also saving fuel. The tool integrates trajectory-based automation; convective weather modeling that predicts the growth and movement of storms; and algorithms to automatically compute minimum-delay routes around bad weather. Researchers and U.S. airlines are engaged to conduct field trials to demonstrate its payoffs under real-world air traffic management scenarios. Laboratory simulations and field tests of DWR conducted have shown potential average savings of 10 minutes or, in operating costs, an estimated \$1,700 per flight impacted by severe weather.

3.2 Time Frame and Targets

Given the broad scope of NextGen, there is a comprehensive planning and implementation process for achieving the full range of NextGen benefits. These implementations are currently improving many aspects of the country's aviation operations with individual elements being implemented throughout the next six years. The emissions reductions resulting from NextGen are intended to support the overall aspirational goal of carbon-neutral growth by 2020.

In response to a request from the House of Representatives Committee on Transportation and Infrastructure, Subcommittee on Aviation, the FAA and aviation industry collaborated through the NextGen Advisory Committee (NAC) to establish a set of priorities and develop an



implementation plan (*NextGen Priorities Joint Implementation Plan*⁹) to deliver high priority, high readiness capabilities in four focus areas—Multiple Runway Operations, Performance Based Navigation (PBN), Surface Operations, and Data Communications (Data Comm)—with the FAA committing to specific site implementation plans and industry ensuring operator preparedness in order to take full advantage of NextGen benefits. These priorities will provide operational benefits to the NAS and increased reductions in fuel burn and emissions. The plan summarizes implementation goals with respect to these priorities at specific airports over the next three years, and provides a timeline of capability milestones at each of these locations. Example implementation commitments from this plan include:

- Increased use of wake categorization, improvements for dual and independent parallel runway operations, and reduced separation standards between dependent, dual, and triple runways at multiple locations nationwide by the close of 2017.
- Improved air traffic flow in the Atlanta, Charlotte and Northern California metroplexes using primarily satellite-based navigation and on-board aircraft equipment to navigate with greater precision and accuracy—which will provide a variety of benefits to NAS users across the country, including shorter and more direct flight paths and improved airport arrival rates—by the close of 2017.
- Improved data sharing with stakeholders, refined departure management capabilities, and improved coordination among air traffic control personnel through the use of electronic flight strips by the close of 2017.
- Data Comm departure clearances at 56 airports to provide digital communications services between pilots and air traffic controllers and enhanced air traffic control information to airline operations centers by the close of 2019.

3.3 Expected Emissions Impacts

Since its inception, NextGen efforts have been designed to have an impact on fuel savings and GHG reductions. The FAA has seen improvements in arrival rates, delay times, track miles, and taxi times. One of the NextGen priorities that is expected to translate to direct emissions reductions is Performance Based Navigation (PBN). The implementation of Area Navigation (RNAV) and Required Navigation Performance (RNP) procedures is expected to result in reductions in fuel burn and emissions. The FAA is currently introducing a large number of PBN procedures into the NAS through the Metroplex program.

Metroplex is an effort to implement PBN procedures along with changes in airspace design in large metropolitan areas that include several commercial and general aviation airports. Due to the density of airports and airspace complexity, there are an increased number of interdependencies at these locations, resulting in increased delays, inefficiencies, and impacts

⁹ *NextGen Priorities Joint Implementation Plan* available at http://www.faa.gov/nextgen/media/ng_priorities.pdf





to the environment. The implementation of PBN at these metroplexes is expected to achieve significant savings in fuel burn and carbon emissions. Figure 3-1 on the following page illustrates each of the metroplexes along with estimates of expected fuel and carbon savings.

3.4 Success Highlights

NextGen initiatives have resulted in many success stories that have contributed to the FAA's emissions reduction goals. The FAA estimates that since 2010, NextGen improvements have saved 59 million gallons of fuel and reduced CO₂ emissions by 565 thousand tons, with 170 thousand tons of CO₂ saved in 2014 alone.

Table 3-1 highlights some examples of recent implementations that are contributing to the achievement of fuel burn and CO₂ emissions savings.

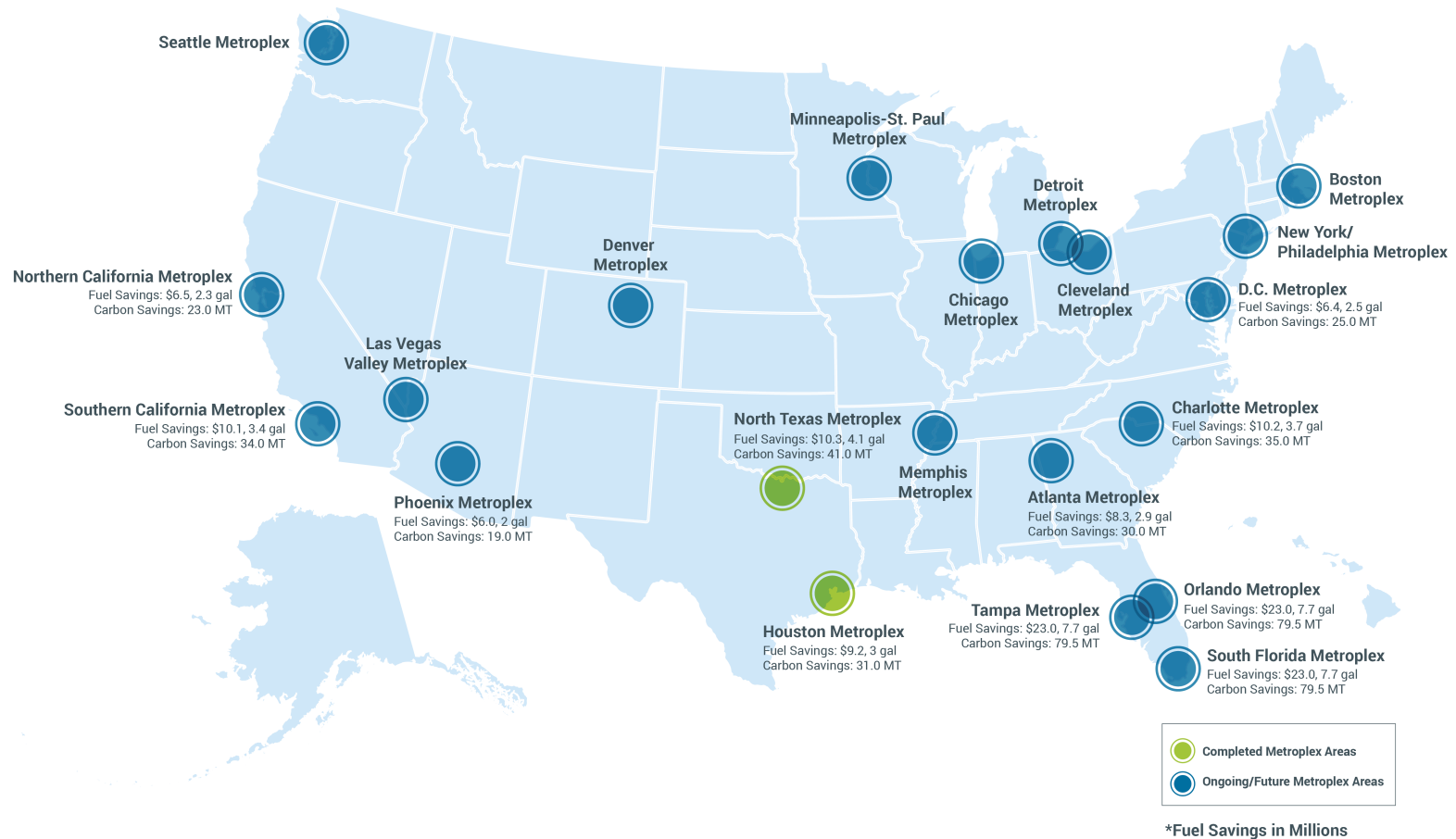
Table 3-1 Completed NextGen improvements with significant fuel and CO₂ savings

Portfolio	Implementation	Operational Benefit	Environmental Benefits in 2014
 Time Based Flow Management	NAS-wide deployment of Traffic Management Advisor with Adjacent Center Metering	Improved aircraft spacing reduces vectoring and holding prior to arrival	<ul style="list-style-type: none"> ▪ Saved 3.7 million gallons of fuel ▪ Reduced CO₂ emissions by 35 thousand metric tons
 Improved Multiple Runway Operations	Dependent approaches at San Francisco	New 7110.308 procedure allows for increased airport throughput during poor visibility conditions	<ul style="list-style-type: none"> ▪ Saved 3.6 million gallons of fuel ▪ Reduced CO₂ emissions by 34 thousand metric tons
 Performance Based Navigation	Transition to PBN Q-routes for cruise operations	New PBN Q-routes add predictability and reduce excess time en route	<ul style="list-style-type: none"> ▪ Saved 6.5 million gallons of fuel ▪ Reduced CO₂ emissions by 62 thousand metric tons
	Equivalent Lateral Spacing Operations (ELSO) implemented in Atlanta	New PBN procedures allow for additional departure routes, increasing throughput and reducing taxi time	<ul style="list-style-type: none"> ▪ Saved 1.7 million gallons of fuel ▪ Reduced CO₂ emissions by 16 thousand metric tons
 Separation Management	Re-categorization of wake separation standards (Wake RECAT) at various airports	Improved wake separation standards have increased departure throughput, reducing time spent waiting on the taxiway	<ul style="list-style-type: none"> ▪ Saved 1.4 million gallons of fuel ▪ Reduced CO₂ emissions by 13 thousand metric tons

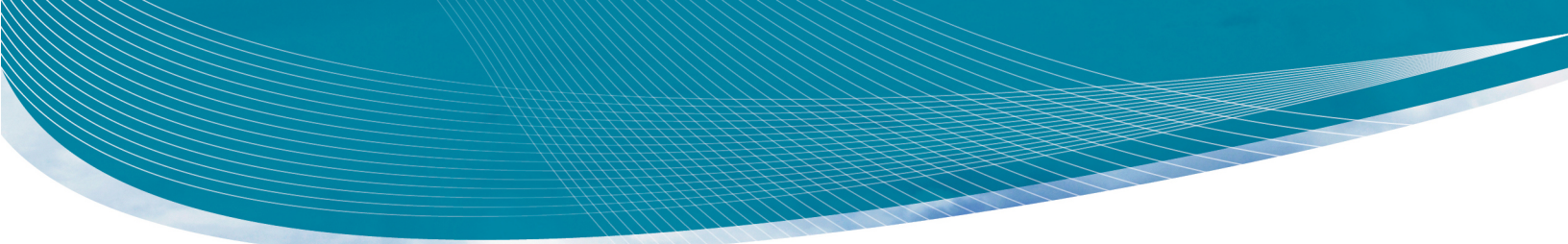
3.4.1 Time Based Flow Management

Time Based Flow Management (TBFM) uses time instead of distance to help controllers separate air traffic. It provides more efficient traffic flow compared to the traditional miles-in-

Figure 3-1 Projected fuel and carbon savings at U.S. metroplexes¹⁰



¹⁰ Savings estimates are annual benefits expected to accrue upon completion of NextGen near-term procedural improvements implemented under the FAA's Metroplex program. They are based on the FAA's preliminary assessment of proposed airspace improvements compared to operations in a year before any improvements were made. More information available at <https://www.faa.gov/nextgen/snapshots/metroplexes/>



trail traffic flow management. TBFM uses the capabilities of the Traffic Management Advisor (TMA), a system already deployed to all en route centers.

Improvements in TMA's trajectory modeler and Time Based Metering (regulating traffic flow by directing aircraft to be at a specific point in space at a specific time) optimize airspace capacity. In particular, facilities using the new Arrival Metering capability were able to save 8 to 10 minutes per metered flight (or an average of nearly 2 minutes across all flights), resulting in benefits to flight operators and passengers of \$200 million per year.

3.4.2 Improved Multiple Runway Operations

In November 2008, the FAA published Order 7110.308, allowing dependent instrument approaches to certain parallel runways with centerline spacing of less than 2,500 feet, known as Closely Spaced Parallel Runways (CSPR). After a thorough safety review and air traffic controller training, San Francisco International Airport (SFO) was added to the list of authorized airports in October of 2012.

The new dual runway approaches at SFO have increased throughput during instrument meteorological conditions (IMC) when only single-runway approaches were possible in the past. The resulting throughput gain has reduced average departure delays by 2.7 minutes and arrival delays by 5 minutes, saving over 3 million gallons of fuel per year.

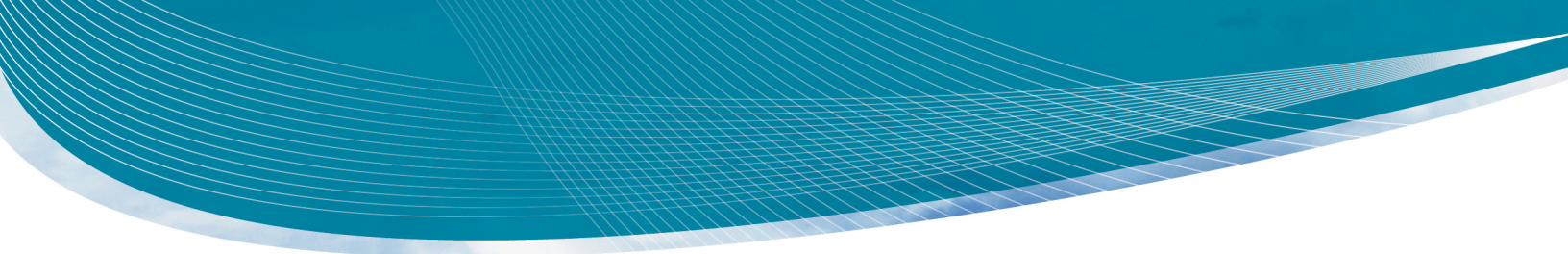
3.4.3 Performance Based Navigation

Q-Routes are published high altitude routes available for use by RNAV-equipped aircraft. They are designed to alleviate airspace complexity in corridors with high traffic volume, and to enhance the predictability of traffic flows in these corridors. By comparing data on flights between the same city pairs, the FAA determined that flights requesting Q-routes flew an average of 14 miles less and experienced an average of 2 minutes less delay than flights using conventional jet routes. This equates to a total savings of 6.5 million gallons of fuel per year, which in turn reduces carbon dioxide emissions by 62 thousand tons.

A different application of PBN is found in the Equivalent Lateral Spacing Operations (ELSO) program that was implemented at Hartsfield-Jackson Atlanta International Airport (ATL), which reduces departure route angles from 15 to 10 degrees without sacrificing aircraft separation. These additional departure routes have increased throughput at the airport, resulting in taxi times that are over 2 minutes shorter per flight. This results in a reduction in fuel burn on the ground of over 1.7 million gallons per year.

3.4.4 Separation Management

Using various navigation equipment and wake performance capabilities, standards and procedures have been created allowing aircraft separation in the NAS to be both enhanced and assured. Using modern data and analytical techniques, new wake turbulence categories have been created in multiple phases of Wake Re-Categorization (Wake RECAT). Memphis International Airport and Louisville International Airport were the first of many airports to



benefit from this effort to reduce the separation of aircraft. Wake RECAT at these two airports has resulted in fuel savings from reduced taxi times of 1.3 million gallons per year, with further savings anticipated as ATL also comes on line.



04 Alternative Jet Fuels Development and Deployment

The USG is actively supporting and facilitating the development and deployment of sustainable alternative jet fuels with lower life-cycle GHG emissions than conventional petroleum fuel.

4.1 Program Specifics

The USG has taken significant steps since 2006 to facilitate the development and deployment of “drop-in” alternative jet fuels. “Drop-in” jet fuel can be used without changes to aircraft systems or fueling infrastructure; it may also reduce aircraft emissions and enhance U.S. energy security.



The Commercial Aviation Alternative Fuels Initiative (CAAFI)—a public-private partnership between the USG, airlines, aircraft manufacturers, airports, and fuel producers—has led efforts in research and development; environmental assessment; fuel testing; and demonstration and commercialization of alternative aviation fuels. CAAFI efforts contributed to the creation of testing protocols and new alternative fuel specifications that have enabled approvals for aviation to use new fuels in commercial service. This is paving the way to large-scale production and use of these fuels. This leadership has also helped make aviation a major target market for the alternative fuels sector.

The USG is taking a multidisciplinary and multi-agency approach to support development and deployment of alternative jet fuels. The U.S. Departments of Agriculture (USDA), Commerce (DOC), Energy (DOE), Defense (DOD), the Environmental Protection Agency (EPA), the FAA, NASA, and the National Science Foundation (NSF) have all made investments to support alternative jet fuel research, development, and production. Aviation is a key strategic target, partner, and market for accomplishing USG goals of promoting bioenergy production, enhancing sustainability and supporting economic development and innovation.

The USG is taking a multidisciplinary and multi-agency approach to support alternative jet fuel research, development, and production.

The USDA is particularly focused on crop and investment programs to support aviation fuel production. The DOE is focusing research funding on the development of new and more efficient biomass conversion technologies to produce alternative jet fuel. The USDA, DOE, and the FAA have jointly signed a Farm to Fly 2.0 cooperation agreement alongside the commercial and business aviation community to focus efforts on enabling the creation of a supply chain and production infrastructure to support a goal of one billion gallons of alternative jet fuel to be used by U.S. aviation by 2018.

In a complementary effort, the President directed the U.S. Navy, DOE, and USDA to make investments in the construction and operation of three biorefineries that will produce up to 100 million gallons of cost competitive alternative diesel and jet fuel beginning in 2016. The FAA and DOD are working together with industry to coordinate and fund alternative jet fuel testing activities that support fuel approval. NASA, the FAA and the U.S. Air Force are leading efforts to understand the benefits of alternative jet fuels on emissions that impact air quality and contrail formation.

The DOE has also become a key government contributor to aviation alternative fuels efforts with research & development, fuel testing, and fuel production investments. The U.S. Renewable Fuel Standard (RFS) mandates the use of 36 billion gallons of renewable fuels by 2022, but does not mandate jet fuel production. However, the EPA has ensured that alternative jet fuels can receive credit toward the volume requirement, thereby enhancing the potential commercial value of the qualified fuels and creating further incentive for production.

4.2 Time Frame and Targets

The FAA has set an aspirational goal for U.S. aviation to use one billion gallons of alternative jet fuel per year by 2018, displacing one billion gallons of petroleum jet fuel. The U.S. Air Force has a goal of being ready to cost-competitively acquire 50 percent of its domestic aviation fuel from domestically sourced 50/50 alternative fuel blends by 2016.¹¹ The U.S. Navy has a goal to have 50 percent of the naval

The FAA has set an aspirational goal for U.S. aviation to use one billion gallons of alternative jet fuel per year by 2018, displacing one billion gallons of petroleum jet fuel.

¹¹ More information available at <http://www.safie.hq.af.mil/shared/media/document/AFD-091208-027.pdf>

fleet's total energy consumption from cost competitive alternative sources by 2020.¹² It is a legal requirement that alternative fuels purchased by the USG be produced in a manner that has a lower GHG footprint than conventional petroleum-based fuels.¹³ The Farm to Fly 2.0 agreement has been signed by the FAA, USDA, DOE, and the aviation industry. It formalizes the intent of the parties to "work together to enable commercially viable, sustainable bio-Jet Fuel supply chains in the U.S. that are able to support the goal of one billion gallons of bio-Jet Fuel production capacity and use for the Aviation Enterprise by 2018."

In general, for an alternative jet fuel to be broadly used by commercial aviation, it needs to be approved by the widely recognized industry standards setting organization ASTM International. To date, ASTM has approved three alternative jet fuels that use vegetable and waste oils, fats, and greases; sugars; and lignocellulosic biomass as raw materials. The approval of additional alternative jet fuels is being pursued to ensure that an even wider range of feedstock and fuel producers have access to the jet fuel market, increasing the chances of reducing cost and providing greater opportunity to meet U.S. environmental goals. In 2014, the FAA worked with industry and with the Brazilian government to facilitate ASTM approval of sugar-derived alternative jet fuel.

The FAA, DOD, and NASA continue to collaborate with industry to advance additional fuel pathways that could more cost effectively convert materials to alternative jet fuels. Once sufficient testing is completed, ASTM is expected to consider approval of the next fuel types, in 2015 and 2016. These fuel pathways could use a wide range of feedstocks, including alcohols, which are then upgraded to jet fuel. A half dozen fuel pathways are also under development and testing and being considered for approval. The USG will continue to examine feedstocks that could be used to create jet fuel, focusing on those that have a minimal impact on land use, fresh water supply, and food crops.

4.3 Expected Emissions Impact

The fuel production pathways approved for use to date provide a range of possible life-cycle GHG benefits. Alternative fuel analyses conducted by the PARTNER Center of Excellence have shown reductions of up to 80 percent life-cycle GHG emissions for some renewable alternative jet fuel pathways such as sugar-based Synthesized Iso-paraffins (SIP) or fuel from lignocellulose via the Fischer-Tropsch (FT) process. Many oil-based Hydroprocessed Esters and Fatty Acids (HEFA) pathways show approximately a 50 percent reduction in GHG emissions.¹⁴

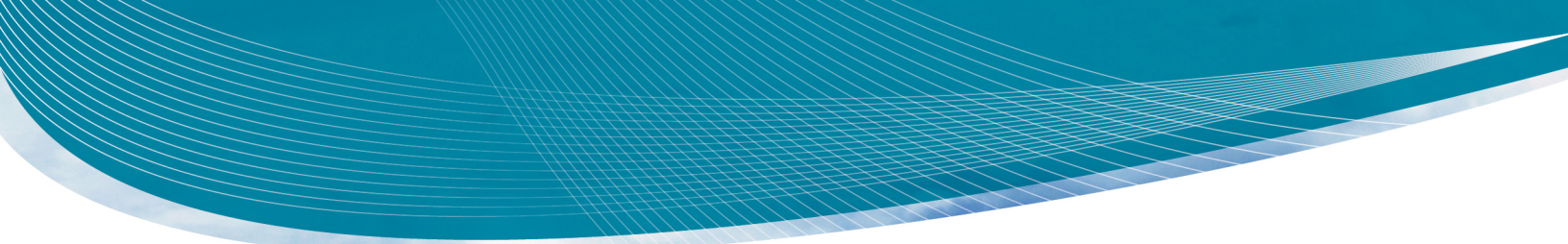
For the U.S. RFS, the EPA has also evaluated the lifecycle greenhouse gas emissions associated with a number of jet fuel pathways produced from renewable biomass.¹⁵ The agency's assessments, which determine the legal eligibility of different fuel pathways for tradable credits

¹² More information available at <http://greenfleet.dodlive.mil/files/2010/10/Navy-Energy-Vision-Oct-2010.pdf>

¹³ "Energy Independence and Security Act of 2007", Section 526, One Hundred Tenth Congress of the United States of America, 2007.

¹⁴ Stratton RW, Wong HM, Hileman JI (2010) Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuel, Version 1.2. Cambridge, Massachusetts: PARTNER/MIT

¹⁵ For the list of existing fuel RFS pathways see: <http://www.epa.gov/otaq/fuels/renewablefuels/new-pathways/approved-pathways.htm>



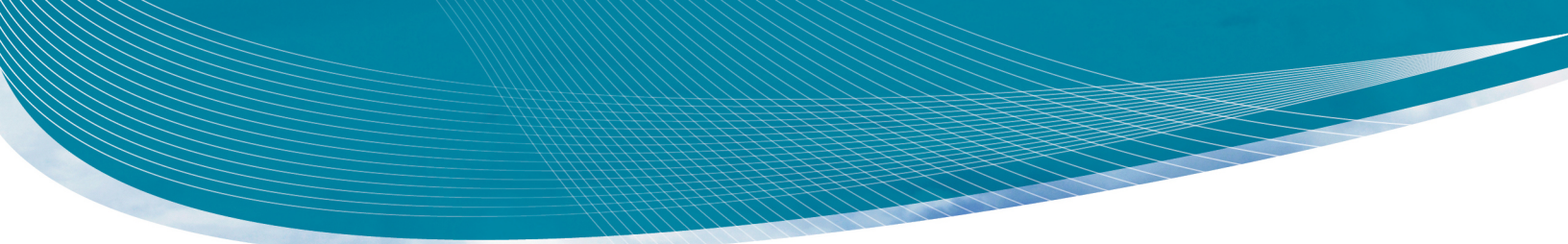
under the RFS program, have found that HEFA jet fuels produced from soybean oil, oil from annual cover crops, algal oil, biogenic waste oils/fats/greases, non-food grade corn oil, or camelina sativa oil reduce lifecycle GHG emissions by at least 50% compared to a 2005 petroleum baseline. The EPA also determined that jet fuel produced from a number of cellulosic feedstocks achieves a 60% GHG reduction compared to the same baseline.

These fuels also demonstrate potentially significant reductions in SO_x and particulate matter (PM) emissions that impact air quality and contrail formation. NASA continues efforts in characterizing the emissions of alternative fuels through both ground and flight testing. Recently, NASA completed the second Alternative Fuel Effects on Contrails and Cruise Emissions (ACCESS) flight campaign. During this flight campaign, NASA, along with international partners the German Aerospace Center (DLR) and National Research Council of Canada (NRC), gathered critical data that helps to quantify the effects of these fuels on the environment and may aid in the development of cleaner aircraft fuels of the future.

4.4 Success Highlights

The following are several examples of progress and successes in the development of sustainable alternative fuels for aviation.

- In April 2013, the USDA and the FAA joined with industry partners from Airlines for America (A4A), Aerospace Industries Association (AIA), Airports Council-North America (ACI-NA), National Business Aviation Association (NBAA) and the General Aviation Manufacturers Association (GAMA) in an expanded “Farm to Fly 2.0” collaboration “to enable commercially viable, sustainable bio-Jet Fuel supply chains in the U.S. that are able to support the goal of one billion gallons of bio-Jet Fuel production capacity and use for the Aviation Enterprise by 2018.” In July 2014, the DOE also signed on as a partner to the agreement. A recent concrete outcome is the application of the feedstock readiness measurement tool to a large number of feedstocks to inform the Farm to Fly working group about availability and feasibility of the key raw materials for alternative fuel production.
- In September 2013, the FAA established the Aviation Sustainability Center (ASCENT), a Center of Excellence for Alternative Jet Fuel and Environment. ASCENT continues the tradition of university research started by PARTNER with an expanded focus on alternative jet fuels. ASCENT has had considerable congressional interest. Within the FY2014 budget, the FAA will fund ASCENT at a \$10M level. ASCENT Project number 1 focuses on examining the potential of regional supply chains within the United States to meet U.S. goals for alternative jet fuel production and chart a path for accomplishing this production.
- In June 2014, the standard-setting organization ASTM International approved a third alternative jet fuel known as Synthesized Iso-Paraffins for commercial use up to a 10 percent blend level. This approval follows previous approvals for FT and HEFA fuels. It



enables the use of alternative fuels produced from plant sugars and provides an estimated 80 percent reduction in life-cycle GHG emissions. The FAA's CLEEN Program supported key testing that enabled the approval of SIP. Additional fuels are currently undergoing testing and evaluation with FAA support for future approval by ASTM International.

- U.S. commercial airlines have announced agreements for purchase of sustainable alternative jet fuels. United Airlines will take delivery of 5 million gallons per year of HEFA fuel from waste oils from Altair Fuels for use at Los Angeles International Airport beginning in 2015. Southwest Airlines has announced plans to purchase 3 million gallons per year for San Francisco, CA airports from Red Rock Biofuels beginning in 2016. Additional commercial announcements are anticipated.
- In September 2014, the USDA, DOE, and the U.S. Navy announced awards to support construction of three production facilities to produce “drop-in” aviation and marine biofuels to power military and commercial transportation. The three agencies are investing up to \$510 million over three years. The DOE and DOD are utilizing the Defense Production Act Title III, which allows the U.S. to invest in strategically significant industries. The USDA plans to provide its contribution through the use of its Commodity Credit Corporation. Beginning in 2016, the three facilities are expected to produce as much as 100 million gallons of fuel per year at an average cost of \$3.50 per gallon.
- The DOE Bioenergy Technology Office (BETO) supports development of pilot- and demonstration-scale fuel production facilities that produce fuel to replace the entire barrel of oil, including jet fuel. DOE is planning additional funding of alternative jet fuel development.
- The USG has established formal bilateral cooperation agreements with Australia, Brazil, Germany, and Spain, each of which have strong alternative jet fuel initiatives. The FAA also supports and participates in ICAO's activities on alternative jet fuels including the CAEP Alternative Fuels Task Force.
- The USG is working together with industry to develop a National Alternative Jet Fuels Research and Development Strategy. This strategy is planned to be released by the Committee of Technology under the National Science and Technology Council. It is intended to mobilize the stakeholder community and enhance national research and development coordination in support of alternative jet fuel development and deployment.

The image shows a magnifying glass with a black handle and silver rim, positioned over a series of blue and yellow vertical bars in a bar chart. A red and blue line graph is overlaid on the chart, showing fluctuating data points. The background is a collage of various charts and graphs in shades of blue, green, and yellow.

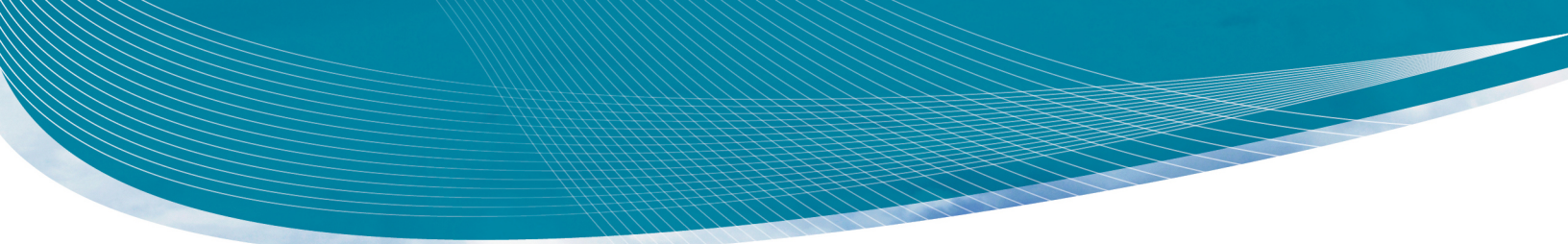
05 Policies, Standards, and Measures

The USG is actively pursuing the development of policies, standards, and measures that would supplement efforts in technology, operations, and alternative jet fuels to further reduce aviation emissions.

5.1 CO₂ Standard

The USG is committed to the development of a meaningful CO₂ standard in ICAO for implementation in the U.S. under the Clean Air Act. In this regard, ICAO/CAEP is currently working toward adopting a meaningful CO₂ standard for aircraft with support from the USG and industry and environmental stakeholders. The primary aim of the CO₂ standard is to incentivize faster development of technology and serve as a basis for ensuring that less efficient aircraft and engine technologies are eliminated over time.

In support of the international aircraft CO₂ standard development, the USG has contributed to the work during all phases, including the development of the aircraft CO₂ metric measurement system and potential regulatory levels, all of which were aimed to be economically reasonable, environmentally beneficial and take into account interdependencies with other standards. Currently, the USG plays a critical role in taking the work further by conducting the analysis of the costs of possible CO₂ standard regulatory levels. This analysis takes into account feasible



CO₂-improving technologies that aircraft could adopt in order to meet the potential CO₂ regulatory levels under consideration. Efforts by the USG are also underway to support the completion of the international certification requirement for the standard, which will ultimately be promulgated as domestic rules. Domestically, the EPA is moving forward with a rulemaking process that may result in findings regarding aircraft GHG emissions. The EPA plans to issue an Advanced Notice of Proposed Rulemaking (ANPRM) to provide an overview of ICAO/CAEP efforts in establishing a global aircraft CO₂ standard and the potential use of the Clean Air Act to implement a corresponding aircraft CO₂ emissions standard domestically. The ANPRM is intended to provide transparency and the opportunity for public comment.

5.2 Global Market-Based Measure

In October 2013, the 38th ICAO Assembly adopted a comprehensive climate change resolution (A38-18). This resolution created a commitment, among others, to develop a global market-based measure (GMBM) to address GHG emissions from international aviation. The USG strongly supported the final resolution and is committed to pursuing development of a proposal for a GMBM to serve as a gap filler to address international aviation GHG emissions. International collaboration with States, industry, and NGO stakeholders has been instrumental to moving the process forward.

Specifically, the USG is actively engaged, participating, and providing resources toward the development of the GMBM through analyses of potential design elements of a GMBM, estimated CO₂ emissions, and potential impact of the GMBM on international aviation. The USG participates in the CAEP GMBM Technical Task Force (GMTF) to further examine design elements of a GMBM, such as systems used to monitor, report, and verify emissions, and define criteria of emissions units that would be eligible for international aviation. The USG also participates in the Environmental Advisory Group (EAG), established by the ICAO Council to oversee work on the GMBM proposal development and provide recommendations to the Council. The USG leads analytical and modeling efforts while working with other states to guide the direction of development of the GMBM. The USG will continue to provide support to complete the work that is necessary to the GMBM's successful development and implementation.

5.3 NextGen Environmental Management System

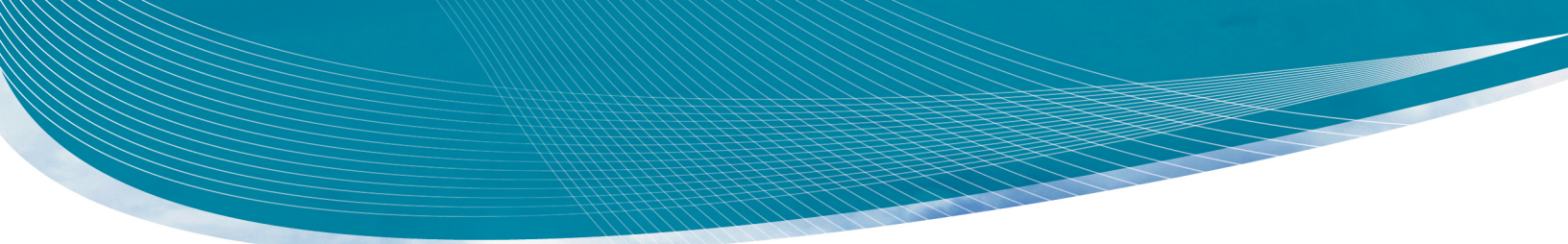
The FAA has developed and is improving upon a NextGen Environmental Management System (EMS) Framework. The EMS will assist in measuring progress toward NextGen environmental goals and obtaining input from stakeholders (e.g., airports, airlines, and manufacturers) on improving environmental performance (e.g., reducing fuel burn and emissions from aviation). With the use of analytical models and information from stakeholders, the FAA can provide transparency and information regarding progress toward goals.



06 Scientific Understanding and Modeling/Analysis

The USG conducts a multi-faceted research program to better understand the environmental impacts of aircraft, including climate impacts from GHG and non-GHG emissions. Emissions of NO_x , water vapor, and particulate matter from aircraft engines interact with the background atmosphere to produce contrails, changes to ozone and methane and secondary effects on cloud formation and destruction. The FAA supports research that will use satellite-derived contrail distributions to estimate the warming impacts of contrails more realistically. This data will help validate results from computer models that are being used to simulate contrail impacts. FAA-supported research will continue to lead to better understanding of current and future climate impacts of NO_x emissions. Specifically, rigorous computer modeling efforts that capture cascading physical processes from smaller to larger scales are underway.

Better understanding and quantification of climate impacts from research are continually being implemented in the FAA modeling and analysis tools to capture the costs and benefits of various policy options. The analytical methods and models used to assess the environmental impacts are regularly enhanced and improved. These tools are not only used to inform decision making but also to quantify the benefits of operational changes, future use of alternative jet fuels, and technology improvements in a consistent framework in addition to noise and air quality tools to better identify interdependencies and tradeoffs in mitigations.



One analysis conducted by the FAA explores how expected advancements in airframe and engine technology, alternative fuels, and operational improvements will propel the U.S. aviation sector towards USG environment and energy goals even with expected growth in operations. The study aims to provide insight into what, if any, gaps may need to be overcome when comparing sector's current environmental performance with its goals, thus allowing the FAA to better identify and prioritize the mitigation solutions that should be pursued. The analysis approach and results are presented in the following sections. As the underlying tools and assumptions are improved, this analysis will be refined and updated.

6.1 Analysis Background

The study methodology consists of developing a baseline (without action) scenario from an aviation forecast, processing this scenario in an environmental consequence tool, and applying system improvements to generate an expected results scenario that reflects the emissions impact of selected measures. Note that this is a system-wide analysis and thus the programs mentioned in prior sections of this action plan are not directly modeled as might be done in a “bottom-up” analysis. Rather, the study aims to capture the level of emissions reductions that can be expected from these system improvements in the aggregate.

6.1.1 Forecasting

A seat class forecast was developed in coordination with the FAA Office of Aviation Policy and Plans (APO). This section describes the primary components of the forecasting process: (1) the Benefits Assessment U.S. Common Operations Database (COD) and (2) the Growth and Retirement process based largely on the FAA Terminal Area Forecast (TAF) and the CAEP Forecast and Economics Support Group (FESG) forecast.

Creation of the Benefits Assessment U.S. Common Operations Database of 2010 Flight Activity

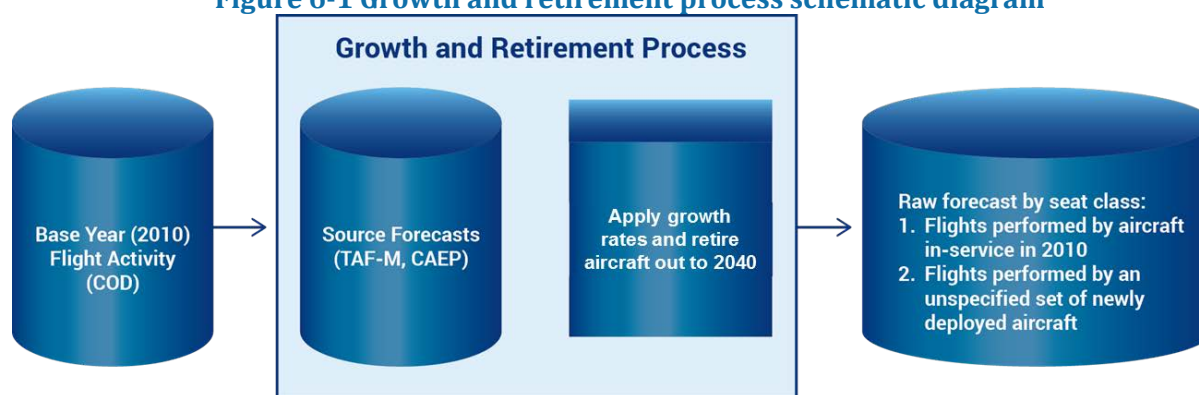
The Benefits Assessment U.S. COD is a radar-derived record of flight activity in 2010 and is a primary input into the study's flight forecasting process. The COD is derived from the FAA's radar-based Traffic Flow Management System (TFMS), which captures most flights controlled under instrument flight rules. TFMS excludes: (1) most uncontrolled (visual) flights and (2) helicopter flights.

Growth and Retirement Process

The seat class forecasting process consists primarily of two steps: (1) growing the set of flights in the COD according to exogenous source forecasts, and (2) retiring aircraft to account for turnover in the fleet. These two processes—Growth and Retirement—are accomplished via a collection of databases and processing modules, of which the majority are in the public domain or in development at the FAA. Among these are the FAA Terminal Area Forecast (TAF), CAEP

FESG retirement curves, and CAEP Fleet and Operations Module (FOM). The TAF is the FAA's official forecast and is updated annually.¹⁶ The TAF covers domestic U.S. operations and U.S. international departures and arrivals. The initial in-service fleet is retired in future years according to CAEP FESG retirement curves. The FOM is a database processing application that outputs a forecast database containing: (1) flights performed by the initial (2010) in-service fleet and (2) flights performed by an unspecified set of newly deployed aircraft in a growth and replacement (G&R) fleet to be assigned subsequently in the modeling process. Figure 6-1 illustrates the Growth and Retirement Process.

Figure 6-1 Growth and retirement process schematic diagram



6.1.2 Environmental Modeling

A pre-release version of the Aviation Environmental Design Tool (AEDT) Version 2b was used to process a baseline scenario of forecasted flights assuming no system improvements as defined below:

- Airframe and engine technology did not advance but current vintage (circa 2010) aircraft were used for fleet growth and replacement.
- Operational improvements had no net system improvement effect but were sufficient to maintain operational inefficiency (i.e., delay) at recent historical levels.
- No alternative fuels were consumed.

The baseline scenario is not equivalent to the kind of “No-Investment” scenario that would be appropriate for a business case analysis. Analyses have shown that, without investment in NextGen, excess times per flight would be expected to eventually rise above recent historical levels.¹⁷ The study accounts for system improvements in post-AEDT processing, as described in the following section.

¹⁶ More information available at <https://aspm.faa.gov/main/taf.asp>

¹⁷ More information available at http://www.faa.gov/nextgen/media/Business_Case_for_NextGen_2013.pdf

6.1.3 System Improvement Assumptions

In the context of the analysis, “system improvement” denotes new technologies, infrastructure, or procedures that result in a net improvement in per-flight environmental and energy performance relative to historical levels. New technologies that only maintain system performance at historical levels are not considered “system improvements” in the context of the study. The study methodology considers three broad categories of “system improvements”: (1) airframe and engine improvements, (2) operational improvements, and (3) alternative fuels. Multiple estimates for these improvements are represented in the analysis in order to provide a range on the output results that reflects uncertainty in the input assumptions.

Airframe and Engine Improvements

The project aircraft included in the system improvement scenario are based on technology packages assessed as part of the FAA’s CLEEN program. These packages consist of CLEEN-funded technologies as well as other public domain and proprietary industry technologies potentially available in the CLEEN timeframe, including NASA N+1 and N+2 technologies. The vehicles were generated and assessed in the Environmental Design Space (EDS), an FAA-funded aircraft design and assessment tool.¹⁸ In the system improvements scenario, these vehicles were deployed into the growth and replacement fleet, resulting in emissions savings in future operations compared to the 2010 in-service fleet. Moderate and aggressive technology scenarios were developed for this analysis in order to reflect uncertainty in vehicle performance (i.e., technology evolution) and the rate of technology insertion into the fleet.

Operational Improvements

The system improvements scenario is idealized in terms of operational performance in that flights progressed over the analysis period toward great-circle flight paths—i.e., aircraft flew the shortest possible lateral distance between origin and destination—as well as unimpeded travel where no delay during the taxi phase is incurred. These operational conditions are not likely to be achievable in practice, but rather illustrate the potential for improvement with respect to spatial efficiency and idle time.

The results also include data points reflecting quantitative assessments performed by the FAA NextGen Systems Analysis & Modeling Office to estimate the expected impacts of NAS modernization. These assessments aid with the selection, prioritization, and evaluation of NextGen technologies, procedures, and financing mechanisms. They also support NextGen planning documents, such as *The Business Case for the Next Generation Air Transportation System*.¹⁹ The data points are included in the results in order to benchmark the idealized assumption for operational improvements.

¹⁸ More information available at http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/eds/

¹⁹ *The Business Case for the Next Generation Air Transportation System* available at <http://www.faa.gov/nextgen/media/BusinessCaseForNextGen-2014.pdf>

Alternative Fuels

The system improvement scenarios leverage the Billion Ton Study from the U.S. Department of Energy.²⁰ This study quantified the amount of biomass that could be produced between now and 2030 within the continental United States from agricultural/forestry industry activity residues and wastes, as well as from dedicated energy crops. The study used an agricultural policy modeling system of U.S. agriculture, including both crops and livestock, that is based on data from the USDA.

Two of the cases from the Billion Ton Study are used for the system improvement scenarios. The first considers a nominal biomass price of \$40/ton, which results in 243 million tons of biomass being available in 2030 from agricultural residues and waste (52% of the total biomass), forestry residues and wastes (34%), and energy crops (14%). The second examines a nominal biomass price of \$60/ton, which results in 767 million tons of biomass being available in 2030 from energy crops (52% of the total biomass), agricultural residues and waste (35%), and forestry residues and wastes (13%). These two scenarios were combined with assumptions that one third of the biomass would be converted to alternative jet fuels at a conversion efficiency of 45 gallons/ton. This yields 3.6 and 11.5 billion gallons of alternative jet fuel per year in 2030, respectively, for the two biomass prices. The Billion Ton Study also considered a high yield scenario wherein crop yields increased by as much as 4% per year. Under this scenario and the aforementioned assumptions, there would be 14.7 billion gallons of alternative jet fuel available in 2030.

For the purposes of the system improvement scenarios, the fuels were assumed to provide a life cycle CO₂ emissions reduction of 75% relative to conventional jet fuels.²¹ Finally, linear extrapolation was used from 2030 to 2050, which roughly corresponds to an annual growth in yields of 3%.

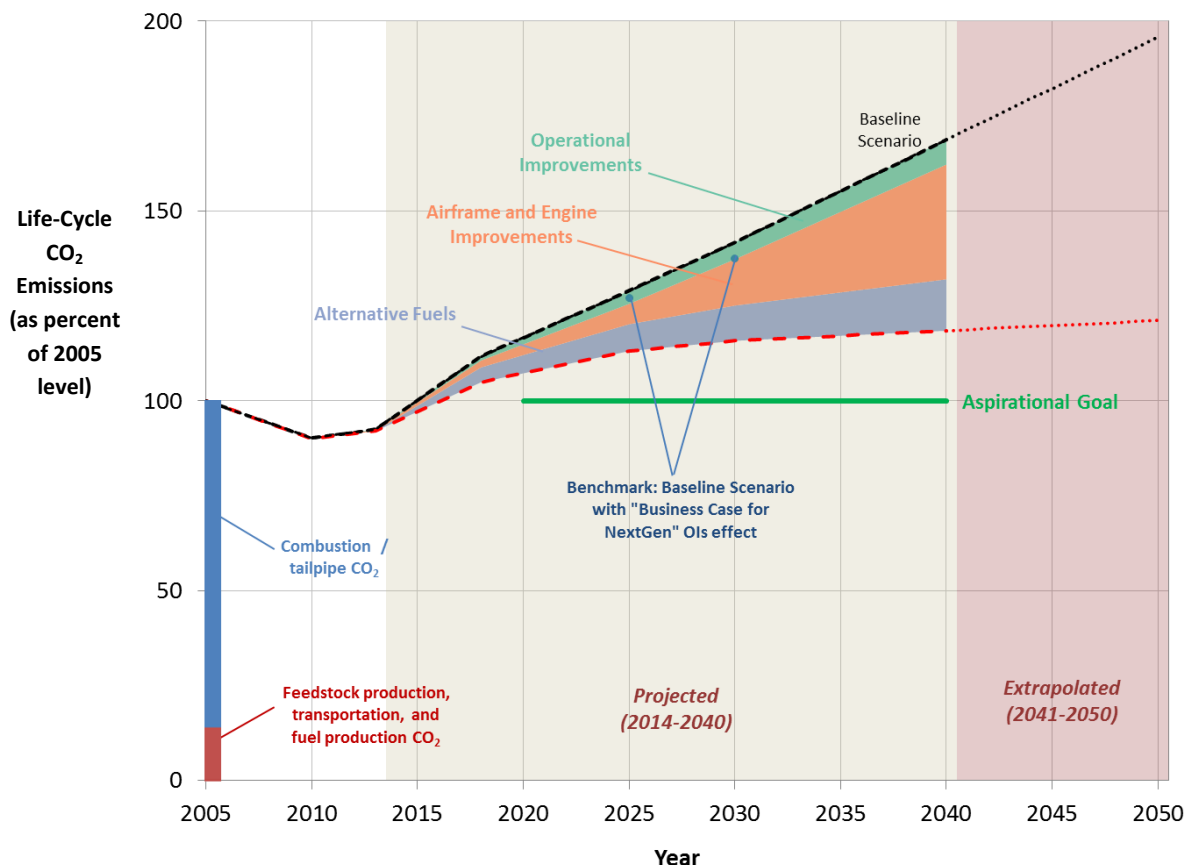
6.2 Analysis Results

Figure 6-2 and Figure 6-3 present the system performance results for the baseline and system improvement scenarios as compared to the FAA aspirational goal of carbon-neutral growth by 2020 relative to 2005 levels. The moderate system improvement assumptions for technology and alternative jet fuel are represented in Figure 6-2, and the aggressive system improvement assumptions are represented in Figure 6-3. A life-cycle basis for computing CO₂ emissions is used rather than relying on tailpipe emissions alone; without this interpretation, alternative jet fuels would not have a large effect on the relative carbon-dioxide intensity associated with jet fuel consumption. The division between combustion and non-combustion CO₂ emissions for conventional jet fuel is illustrated in the callout bar chart in the figures.

²⁰ Billion Ton Study available at http://www1.eere.energy.gov/bioenergy/pdfs/billion_ton_update.pdf

²¹ This reduction is in line with the CO₂ life cycle calculations of waste and energy crop conversion to FT jet fuel from Stratton et al. (2010), available at <http://web.mit.edu/aeroastro/partner/reports/proj28/partner-proj28-2010-001.pdf>

Figure 6-2 Projected life-cycle CO₂ emissions impacts – moderate system improvement scenario²²

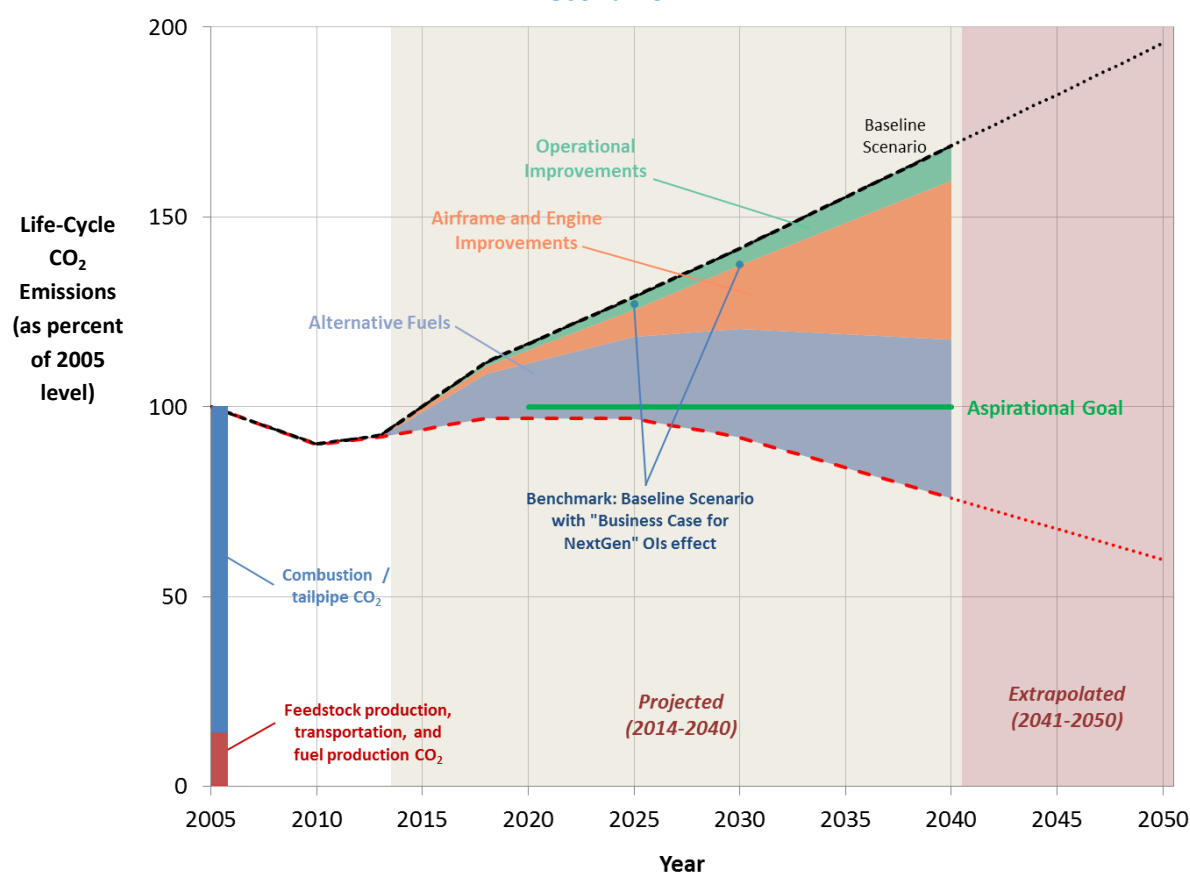


The analysis indicates an emissions reduction potential from the baseline scenario of approximately 53 percent in 2040 for the moderate improvement scenario and 98 percent in 2040 for the aggressive improvement scenario due to airframe and engine improvements, operational improvements, and alternative jet fuels. The results shown in the figure represent all U.S. operations, domestic and international. Regarding the NextGen benchmark data points, the assessment shows a benefit equivalent to 48 percent and 85 percent of the idealized operational improvement benefit in the years 2025 and 2030, respectively. Though there are uncertainties in the forecast and system improvement assumptions, the analysis gives an indication of how much progress is needed in order to approach FAA climate and energy-efficiency goals. While the analysis indicates that significant progress can be made toward the USG's aspirational climate goals, challenges remain to reach the levels of operational improvement, technology improvement, and alternative fuel availability reflected in these

²² Note that combustion/tailpipe emissions are those created by the airline industry, while feedstock production, transportation, and fuel production emissions for conventional jet fuel are created by the petroleum extraction and refining industries. The emissions from alternative jet fuels would result in a net reduction in the CO₂ emissions from fuel production and use. The scenario does not imply that the upstream emissions are attributable to airlines, rather than to jet fuel producers and others in the supply chain.

scenarios, and it will take concerted USG and aviation industry efforts to work through these challenges. Significant work is being done under the Aviation Sustainability Center (ASCENT)—a Center of Excellence for Alternative Jet Fuel and Environment—to provide additional analyses to improve upon the assumptions that underpin this study. Specifically, ASCENT has initiated research projects in the areas of alternative jet fuel supply chains, aircraft technology modeling, and rapid fleet-wide assessment. As the analysis assumptions are refined through this work, further insight will be gained into the contribution of various improvement areas to the overall environmental performance of U.S. aviation and into the gaps that need to be overcome in pursuit of aspirational goals.

Figure 6-3 Projected life-cycle CO₂ emissions impacts – aggressive system improvement scenario





07 Summary

The United States is committed to addressing the climate impacts of commercial aviation through an integrated strategy of technology, operations, and policy innovation. This action plan details the USG measures to reduce GHG emissions through improved airframe and engine technology, more efficient aircraft operations, and development and deployment of alternative jet fuels, all in support of working towards the aspirational goal of carbon-neutral growth for U.S. commercial aviation by 2020, using 2005 emissions as a baseline. The plan leverages interagency cooperation as well as a number of public-private partnerships to enable a safe, efficient, and sustainable aviation system. The analysis presented in this document shows that significant progress can be made toward the USG's aspirational climate goals through aviation system improvements. This document will be updated on a three-year cycle in order to continue to monitor and report on progress and to communicate further plans for ensuring sustainable aviation growth.